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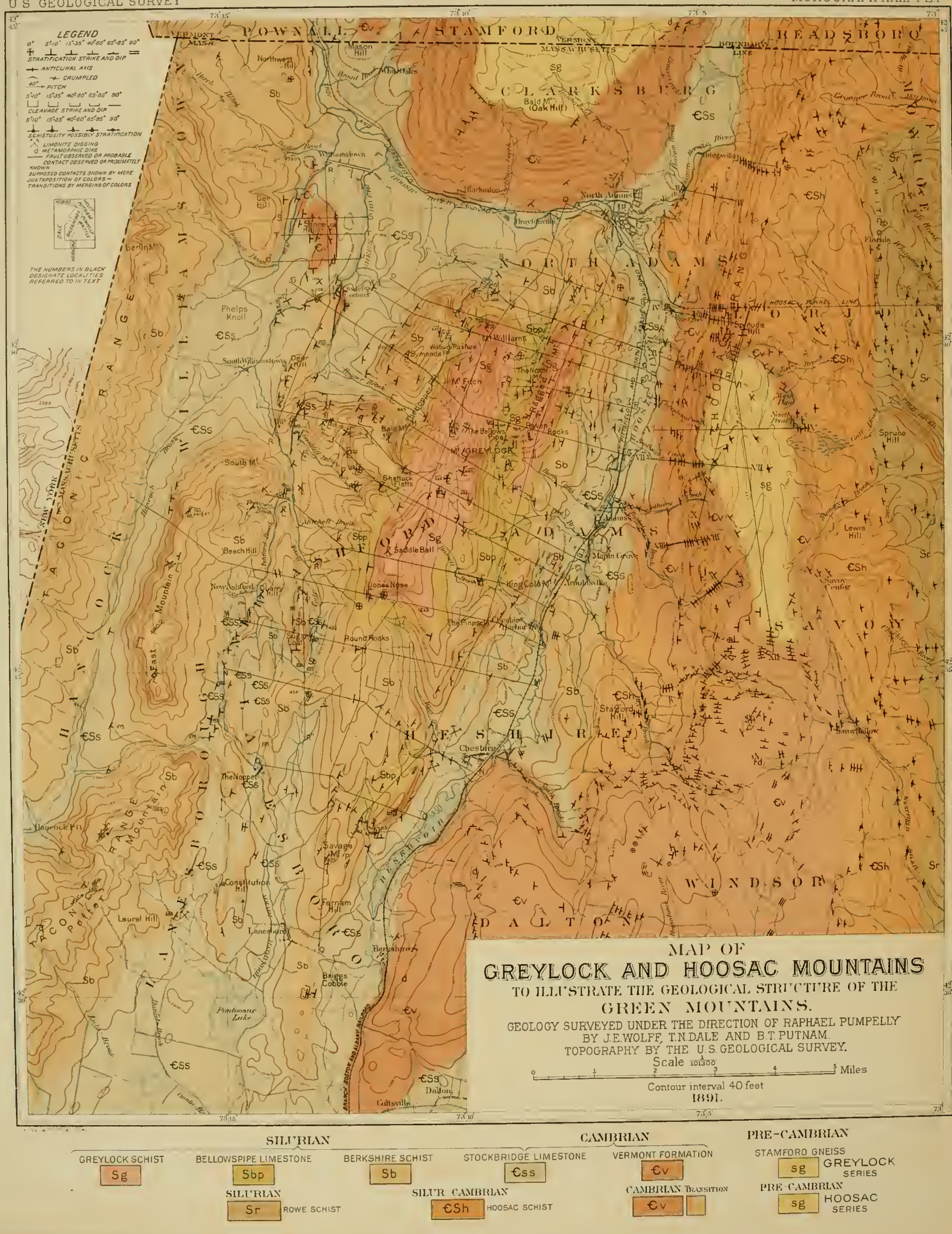
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PITCH
CLEAVAGE STRIKE AND DIP
SCHISTOSITY POSSIBLY STRATIFICATION
LIMONITE DIGGING
METAMORPHIC DIKE
FAULT OBSERVED OR PROBABLE
CONTACT OBSERVED OR PROXIMATELY KNOWN
SUPPOSED CONTACTS SHOWN BY MERE JUXTAPOSITION OF COLORS — TRANSITIONS BY MERGING OF COLORS
THE NUMBERS IN BLACK DESIGNATE LOCALITIES REFERRED TO IN TEXT
POWNALL
STAMFORD
READSBORO
CLARKSBURG
NORTH ADAMS
FLORIDA
ADAMS
SAVOY
CHESHIRE
WINDSOR
DALTON
LANESBORO
WILLIAMSTOWN
NEW ASHFORD
HANCOCK
TACONIC RANGE
VERMONT
MASSACHUSETTS
NEW YORK
North Adams
Williamstown
Blackinton
Braytonville
Briggsville
Mt Williams
Mt Fitch
Mt GREYLOCK
The Bellows Pipe
Ragged Mt
Saddle Ball
Jones Nose
Round Rocks
The Pinnacle
Cheshire
Lanesboro
Berkshire
Dalton
Coltsville
Savoy Center
Spruce Hill
Lewis Hill
Mason Hill
Bald Mt (Oak Hill)
Phelps Knoll
Berlin Mt
East Mountain
Laurel Hill
Constitution Hill
Farnam Hill
Briggs Cobble
Pontoosuc Lake
South Williamstown
South Mt
Beach Hill
Stafford Hill
Maple Grove
King Cole Mt
HOOSAC TUNNEL LINE
HOOSAC RANGE
SILURIAN
GREYLOCK SCHIST Sg
BELLOWSPIPE LIMESTONE Sbp
BERKSHIRE SCHIST Sb
SILURIAN
ROWE SCHIST Sr
CAMBRIAN
STOCKBRIDGE LIMESTONE €ss
VERMONT FORMATION €v
SILUR CAMBRIAN
HOOSAC SCHIST €Sh
CAMBRIAN TRANSITION €v
PRE-CAMBRIAN
STAMFORD GNEISS sg GREYLOCK SERIES
PRE-CAMBRIAN
sg HOOSAC SERIES

DEPARTMENT OF THE INTERIOR

MONOGRAPHS

OF THE

UNITED STATES GEOLOGICAL SURVEY

VOLUME XXIII

WASHINGTON
GOVERNMENT PRINTING OFFICE
1894

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

GEOLOGY

OF THE

GREEN MOUNTAINS

IN

MASSACHUSETTS

BY

RAPHAEL PUMPELLY, J. E. WOLFF, AND T. NELSON DALE.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1894

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Department of the Interior,
U. S. Geological Survey, Archean Division,
Newport, R. I., January 18, 1892.

Sir: I have the honor to transmit herewith a memoir on the Geology of the Green mountains in Massachusetts.

Your obedient servant,

Raphael Pumpelly,
Geologist in charge.

Hon. J. W. Powell,
Director U. S. Geological Survey.

PREFACE.

The following memoir is the result of the fieldwork of the Archean Division of the U. S. Geological Survey in northwestern Massachusetts, during the years 1885, 1886, and 1887.

The conclusions put forth were all arrived at before 1888, but the publication of them was delayed until they should be either confirmed or corrected by the results of further study in southwestern Massachusetts and in central Vermont.

The progress of our survey of western New England has fully confirmed our interpretation of the facts observed in the Hoosac mountain and Greylock area. It has been our intention to keep wholly clear of the Taconic controversy, and to confine our efforts to accurate study and interpretation of structure. In the first part I have given a statement of the sequence and bearing of the results and have advanced some theoretical views in explanation of the sudden disappearance of the Lower Silurian limestone against the western base of the Green mountain anticline. I have also advanced a hypothesis, supported by observation in the northern and southern Appalachians, to explain (through the presence of a previously deeply disintegrated land surface) the apparent conformable transition between Archean or pre-Cambrian gneisses and Cambrian quartzite. This almost insuperable difficulty is met with in many of the great crystalline areas of the world, in passing from Archean or eruptive masses to the clastic crystalline schists.

The second part treats of Hoosac mountain—the central or crystalline range of the Green mountains. The field work was performed by Dr. J. E. Wolff, Mr. B. T. Putnam, and myself. The analysis of the results, the petrographic study, and the presentation are by Dr. Wolff. Mr. Putnam had contributed largely to the sum of the work. His early death in 1886 deprived the Survey of one of its most accurate and thoughtful geologists.

The third part deals with the Greylock synclinorium—made up of the Cambrian-Silurian quartzite, limestones, and schists, which are the offshore time equivalents of the white gneisses and schists of Hoosac mountain. The field work was done by Mr. T. Nelson Dale, assisted in part of the area by Mr. William H. Hobbs. The analysis of the results and the presentation are by Mr. Dale.

As during the first two years we had not yet the benefit of the new topographic map of Massachusetts, our work was delayed by the necessity of making our own maps. This was done in part by Messrs. Putnam and Wolff, assisted by Mr. Yocum. Later, Mr. Josiah Pierce made a detailed topographic survey of the western flank of Hoosac mountain which forms the geographic basis of Pl. IV.

Mr. C. L. Whittle was also connected with the work under Dr. Wolff during the season of 1887.

Mr. William H. Hobbs acted as assistant to Mr. Dale during one season and a part of another in the work on Greylock and was engaged independently during the rest of the second season on the coloring of the northwestern part of the Greylock sheet.

I have mentioned in its proper place the fact that we owe to Mr. C. D. Walcott the determination of the age of our basal quartzite.

R. P.

PART I.

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GENERAL STRUCTURE AND CORRELATION.

By Raphael Pumpelly

GENERAL DESCRIPTION.

The Green mountains, nearly coinciding with the prolongation of the axis of the Archean core of the Appalachians through western New England, stand between the less disturbed fossiliferous Paleozoic strata of New York and the highly crystalline rocks of New England. They consist of three principal structural elements: The Green mountains (Hoosac mountain); the Taconic range, lying several miles to the west; and, between these, the great valley. But the whole region between the Hudson and the Connecticut has very properly been placed by Dana in one mountain system. I shall therefore follow Dana and distinguish between a central or axial ridge, flanked by an eastern belt extending to the Connecticut, and a western belt extending to the Hudson, though what I shall have to say refers mainly to the central belt and the neighboring portion of the western belt.

The Green mountain range is composed of crystalline schists, which our results show to be of Cambrian and Lower Silurian age, resting on pre-Cambrian rocks, and it was long ago shown by Edward Hitchcock to have an anticlinal structure. The western edge of this axial range is, for long stretches, marked by a lofty brow of quartzite, and for this reason the mountains present a very steep flank on the west. At the base of this western flank lies what is known as the valley of Vermont or, in Massachusetts, the Berkshire valley. This valley has a floor of crystalline limestone, often a saccharoidal marble of Cambrian and Lower Silurian age, on which stand long island-like ridges of schist, of Lower Silurian age, and it extends with a breadth of several miles from northern Vermont to Alabama. The schist is everywhere underlain by the limestone, which is marked by the fertility of its soil; and, along its whole length, its wealth of limonite ores has for more than a century formed the basis of important iron industries. In the folded strata of this valley belt in Vermont and Massachusetts, subsequent erosion has left island-like mountains, sometimes of anticlinal, but generally of synclinal structure, with more or less pitch in their axes. Instances of the latter are Eolus (Dorset), Anthony, Greylock, Everett, etc., rising to 1,500 or 3,000 feet above the valley, and surrounded to a greater or less height above the base by the limestone, and heavily capped with the weather-resisting schist. Instances of anticlinal structure are the less elevated pine hill near Rutland and the ridge which connects it with Danby hill in Vermont.

On the west, this limestone valley has for a wall the Taconic mountains, with peaks rising 1,500 to 2,500 feet above the valley. This is a synclinal range of the same Lower Silurian schist, but, having its trough at a lower level, the limestone foundation appears only at the base.

Turning now to the region east of the axis of the Green mountain anticline, we find no great and continuous depression comparable to that of the valley of Vermont until we reach the Connecticut valley; and this is occupied by much later strata—Triassic resting on Devonian. This eastern region is a very roughly mountainous mass of schist, and, though of plateau origin, is crossed by deeply cut transverse valleys, which receive longitudinal tributaries, whose courses are determined in the main by the geologic structure of the territory. All along the eastern edge of the axial belt of the mountains there occur such narrow, longitudinal valleys, and as they contain, more or less continuously, beds of limestone of either Cambrian or Lower Silurian age, they define the eastern limit of the Green mountain range proper, with less topographic but with equal geologic sharpness.

AGE AND STRUCTURE.

In beginning work on the geology of New England, two facts were apparent—that from the Green mountains eastward the rocks were all highly metamorphosed and crystalline; and that only in two or three localities had fossils been found, and in these places the rocks were so much disturbed that it seemed hopeless to use them as starting points for the general work. I became convinced that our hopes of determining the age of the New England rocks lay in using the Green mountains as a bridge. In following this plan we were immediately met by the fact that on the main ridge—our proposed bridge—the rocks are not only highly metamorphosed and their structure the reverse of simple, but that the western edge of the ridge marks an abrupt lithologic change between the character of the rocks of the mountain and those of the valley, with the exception of the younger schists, which in places cap both the axial range and the valley hills. On the west the great limestone and an underlying great quartzite come eastward to the base of the mountain, while a careful reconnaissance showed no trace of these rocks as such upon the mountain, nor of such a combination on the eastern side.

This difficulty, which met the earlier surveys, had led to various hypotheses in which faults and overturns played an important part. And while the rocks of this main ridge were assigned by different eminent geologists to ages ranging from the Sillery[1] to Huronian and Laurentian,[2] the residuum of opinion has been of late in favor of Archean or at least pre-Cambrian age. The problem was undoubtedly too difficult to be solved without more ample means than were at the disposal of our predecessors.

It was evident that our first and hardest work would be to find the key to the structure of the range. For this purpose I sought a region where the western edge should present, instead of a straight line, as many bay-like curves as possible, and where the structure of the ridge itself should show folds with pitching axes. I hoped in such a region to eliminate the difficul-

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[1] Logan colors them as Sillery on the Geological map of Canada, 1866.

[2] C. H. Hitchcock: geological sections across New Hampshire and Vermont. Bull. Am. Mus. Nat. Hist., vol. I, New York, 1884.

ties introduced by possible faults, as well as the temptation to infer their existence; and also in case of pitching folds to get, through radiating cross sections, a knowledge of the true order of bedding.

These conditions were found well presented in the northwestern corner of Massachusetts. Here the western edge of the main ridge coming down from Vermont makes a sharp turn eastward around Clarksburg mountain; then after resuming for several miles a straight southerly course it curves back westward to bend around the Dalton hills. Opposite this bay stands Greylock mountain, which Emmons and Dana had shown to be a great synclinal mass. The greater and higher part of this Greylock mass of Lower Silurian rocks rises to the east of the chord of the arc that is formed by this bay-like curve. Again, Hoosac mountain, east of this bay, exhibits a variety of distinct rocks in folds, the axes of which show a persistent northerly pitch. And in addition to this I hoped for much aid from the great tunnel, which, in 1865, I had examined for the state of Massachusetts. With a length of nearly 5 miles, it pierces the mountain through its whole breadth at a depth of over 1,000 feet, and the fact that the tunnel was driven from both ends and from two intermediate shafts gave assurance that the dumps would supply unaltered material for the petrographic study of the various rocks in all their variation of habit. As there was then no topographic map of the region we were obliged to locate all of our work by transit survey. During the first two seasons, in company with my assistants, Mr. B. T. Putnam and Mr. J. E. Wolff, I made thorough reconnaissances of the area in question, and, to obtain as much light as possible, these excursions were extended southward to the Highlands east of the Hudson and northward to central Vermont.

We had found that the mass of Hoosac mountain consists of a core of coarsely crystalline granitoid gneiss, overlain in some places by a conglomerate, in others by fine grained white gneisses. Above the conglomerate and white gneisses we had found a great thickness of biotitic and sericitic schists, containing either macroscopic or microscopic albite, in both untwinned and simple twinned crystals. At all the contacts of this whole series there appeared distinct structural conformability.

On Clarksburg mountain we had found the same coarse granitoid gneiss, covered, apparently conformably, by a true quartzite. At the base of the Dalton hills the quartzite was found to conformably underlie the great Cambro-Silurian limestone, which in its turn forms the base of Greylock, and this limestone was found to be conformably overlain on Greylock by a great thickness of schists, identical in character with those overlying on Hoosac—here the conglomerate and there the white gneiss—with no intervening limestone or quartzite. Again, we had found that these white gneisses contained apparently interstratified beds of these same schists.

CORRELATION.

Having made it a rule that all correlation of strata and interpretation of structure should be decided solely upon observed structural relations, there was nothing to be done but patiently to work out the structure, step by step, using lithologic similarities as clews only.

The reconnaissances showed that the Green mountains are wholly made up of crystalline schists, and that one or more of the horizons of these must vary in the most protean manner in the external habit of its rocks, while on either side of the range[1] the rocks retain their respective characteristics with relatively little change. One of the earlier observations on the western brow of Hoosac mountain had been the superposition of the coarse granitoid gneiss over the white gneiss at a well-marked contact and with structural conformity of lamination. On the other hand, in the tunnel, this same granitoid gneiss appeared as a central core, farther east than the geologic meridian of the surface outcrop. This core was found in the tunnel[2] to be flanked on each side by the conglomerate overlain by the albitic schist. If the structure were as simple as the tunnel section seemed to indicate it would point to two horizons of the granitoid gneiss, and connect this rock and the white gneiss in age. An important

[1] Dana pointed out in 1872 the abrupt lateral transitions between the quartzite and schists of Berkshire county. (Am. Jour. Sci., 1872, p. 368.)

[2] This tunnel is lined with masonry at irregular intervals to such an extent that a large part of the rock, especially of the more interesting western half, is hidden. The walls are covered to a depth of an inch with soot. In addition to this, geologic work was made extremely dangerous by the fact that the smoke was so dense that even our thirteen torches were invisible across the tunnel, and the noise of trains running 30 miles an hour was not audible until the engine was within a few yards from us. Notwithstanding these difficulties we managed to find the important contacts, except at the western end, where they were bricked over.

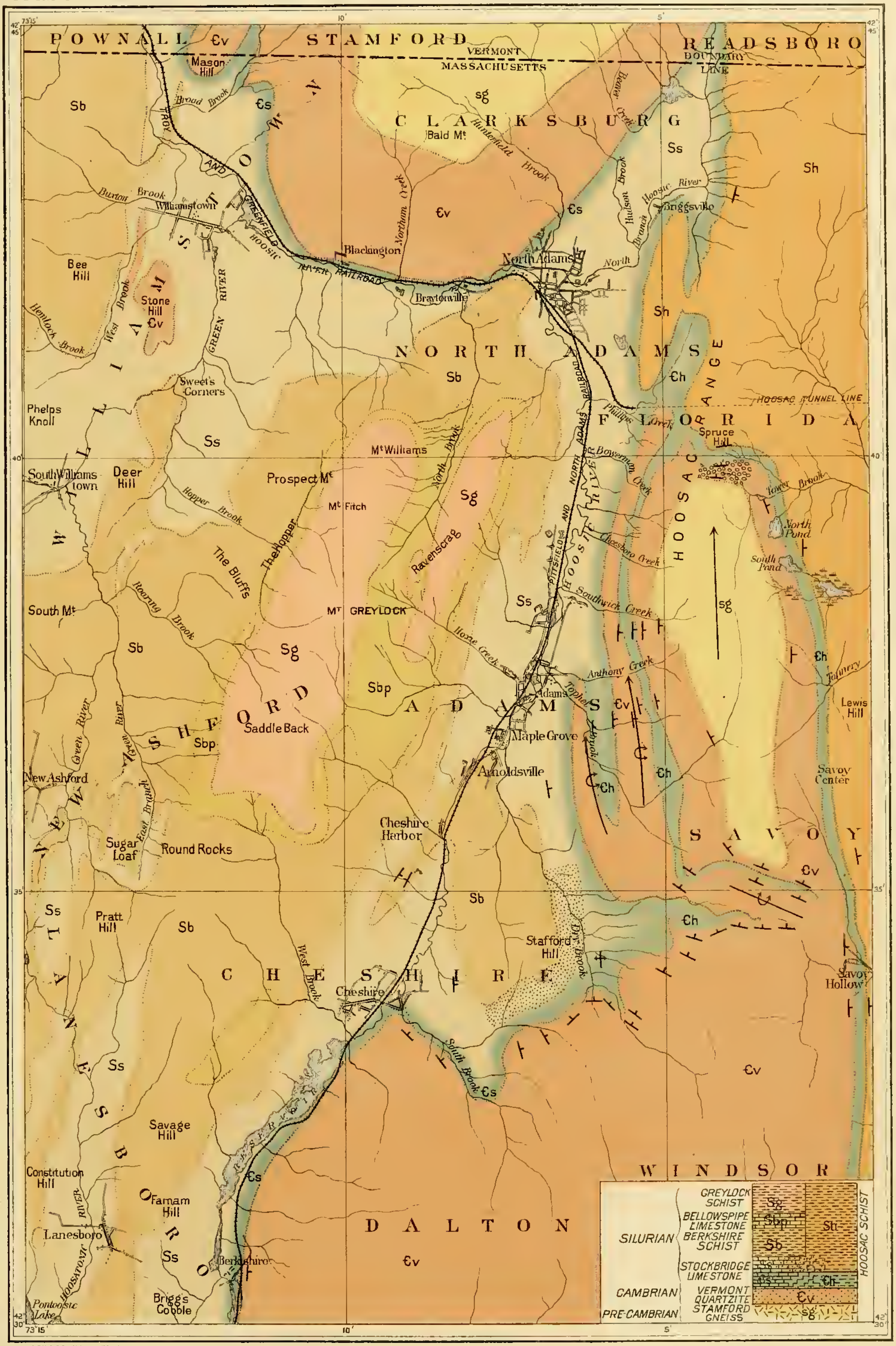
point was therefore gained when the hypothesis advanced to us by Mr. Putnam that the surface exposure of granitoid gneiss was a flat, overturned anticlinal fold was corroborated by Mr. Wolff. Mr. Wolff also discovered that the schist beds in the white gneiss on the western flank belong to the series above the white gneiss, and are simply remnants left in compressed troughs overturned to the west under the overturned anticline just mentioned.

The next step was made by Mr. Wolff in the determination that the white gneisses are clastic rocks, while the coarse granitoid gneiss shows no trace of clastic origin. This pointed to a closer relation between the white gneiss and the conglomerate, from the fact that one or the other was found to overlie the granitoid gneiss. This question also was settled by Mr. Wolff by tracing out the lateral transition from the conglomerate into the white gneiss.

Finally the upward transition from the white gneiss and from the conglomerate into the schist was observed.

Messrs. Putnam and Wolff had observed, and I had traced later at several points on Clarksburg mountain, a strict conformability between the lamination of the granitoid gneiss and that of the overlying conglomerate and quartzite, the continuation of the great quartzite belt of Vermont; and later Mr. Walcott had found, near the same contact, numerous casts of *Olenellus*, showing the lower part of the quartzite to be of Lower Cambrian age. Later, Mr. Wolff, in tracing this quartzite northward along the eastern flank of the granitoid gneiss of Clarksburg mountain, found it to pass by lateral transition along the strike into well-defined white gneisses like those of Hoosac mountain. Later still a similar transition was observed between the true quartzite and the Hoosac white gneiss on the northern side of the Dalton hills.

There still remained to be explained the nature of the relation between the granitoid gneiss and the overlying clastic rocks, and the conformability that exists between the structure of the granitoid and that of the overlying rocks. Prof. Emerson, working on the map in Hinsdale, found an area of granitoid gneiss overlain by the conglomerate, and concluded, from the relation of the two rocks over broad areas, that they are there structurally



SHOWING THE RELATION OF THE GREYLOCK SERIES TO THE HOOSAC MOUNTAIN ROCKS.

BY RAPHAEL PUMPELLY.

Scale $\frac{1}{125000}$

0 ½ 1 2 3 4 5 Miles

1891.

unconformable. At about the same time Mr. Wolff had found the two dikes of eruptive basic rock in Stamford in the granitoid gneiss and at its contact with the quartzite. (Figs. 1 and 2.)

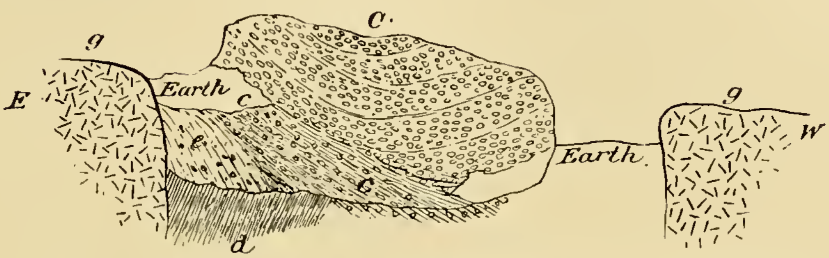


FIG. 1.—The Stamford dike, showing the Cambrian conglomerate deposited in dike fissure; *C*, conglomerate; *c*, lower layers of conglomerate rendered schistose by admixture of material from the altered dike; *d*, diabase of the dike rendered schistose by metamorphism; *e*, altered dike material; *g*, pre-Cambrian granitoid gneiss.

We could hardly have wished for better evidence than that offered by one of these. At the contact the quartzite strikes N. 40° E., dips 50° SE. The dike strikes N. 60° W., between vertical walls; but the rock of the dike has undergone changes that have given it a lamination, and the planes of this strike N. 35° W. and dip 45° easterly. The structure of the granitoid gneiss is here quite irregular and obscure. No trace could be found of the dike cutting into the quartzite, and as this is continuously exposed on both sides, the possibility of its absence by faulting was eliminated. But there is more direct positive evidence in the fact that the quartzite beds thicken and sag down over the dike—indeed, into the dike fissure, as Mr. Whittle and I found by digging. The evidence is conclusive, as I satisfied myself during several visits, that the Cambrian transgression found here a fissure, either open or filled with a rotten dike, which was washed out to a depth of several feet and refilled with beach sand and pebbles, the dark material contributed by the dike increasing toward the bottom. The sudden thickening and sagging of the quartzite over the fissure, taken

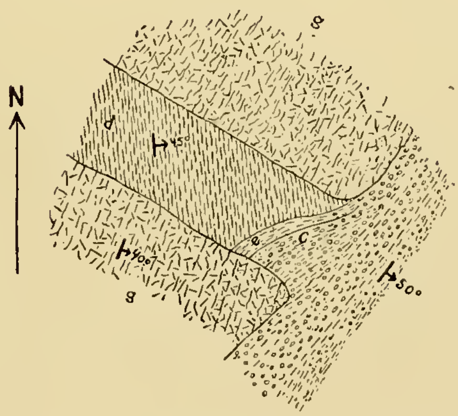


FIG. 2.—The Stamford dike, plan. *c*, conglomerate; *d*, dike rock, metamorphic, with foliation; *e*, altered dike material; *g*, Stamford gneiss.

in connection with the mixture of dike material and sand, and the stopping of the dike at the quartzite, prove sufficiently the pre-Cambrian age of the granitoid gneiss. And this is emphasized by the fact that both the quartzite and white gneiss are frequently conglomerates.

The structural conformability of which I have spoken above is due simply to the generally parallel lamination that has been forced upon the rocks of the region by the folding.

We had now established the fact that in this part of the Green mountains the column in the main range consists of a Lower Cambrian quartzite-conglomerate-white-gneiss formation, resting with a time break upon a coarse granitoid gneiss, and conformably overlain by a great thickness of schists.

Parallel with the study of Hoosac mountain, that of Greylock was carried on by Mr. T. Nelson Dale, assisted, for a time, by Mr. W. H. Hobbs. This mass was shown to consist of a great lower crystalline limestone, overlain by a heavy mass of schists, above which another thick mass of limestone was overlain by still another great mass of schist, the whole column containing about 2,000 feet of limestone, and 2,500 to 4,000 feet of schist. These estimates are based on measurements of areas that have been subjected to lateral pressure, and of course do not claim to represent the original thickness.

Lower Silurian fossils have been found in the continuation of a part of the lower limestone in Vermont. Mr. Dale found the Greylock limestone and schists conformable throughout and exhibiting vertical transitions.

It seemed almost impossible to find points where the actual stratigraphic relation of the limestone to the quartzite could be observed, but I was fortunate in finding such a place on Lachines creek, near Berkshire station. Later, by means of digging, which was done here under Mr. Putnam, it was shown not only that the quartzite and limestone are structurally conformable, but that they are bound together by vertical transition through calcareous flaggy quartzites. We have here in an overturned fold, with easterly dip, the Stockbridge limestone dipping under the older Cambrian quartzite formation. The limestone proper is succeeded toward the quartzite by flaggy quartz schists, and these by a heavy development of schistose calcareous quartzite. East of this the quartzite becomes friable, and has here been excavated as the well-known Berkshire sand. About 100 feet east of this we find an outcrop of vitreous quartzite. The next outcrops—older and 300 or 400 feet eastward and dipping 50° easterly—show a schistose quartzite overlain by an older and more slaty bed of the same; and this by a very coarsely feldspathic quartzite followed by another bed of schistose quartzite, and this by a feldspathic biotite-schist. Representing these in their normal succession we have—

Stockbridge limestone.
Flaggy quartz-schists.
Schistose calcareous quartzite.
Sandy quartzite (friable).
Vitreous quartzite.
Covered (300 or 400 feet).
Schistose quartzite.
Schistose quartzite, more slaty.
Very feldspathic quartzite.
Schistose quartzite.
Feldspathic biotite-schist.

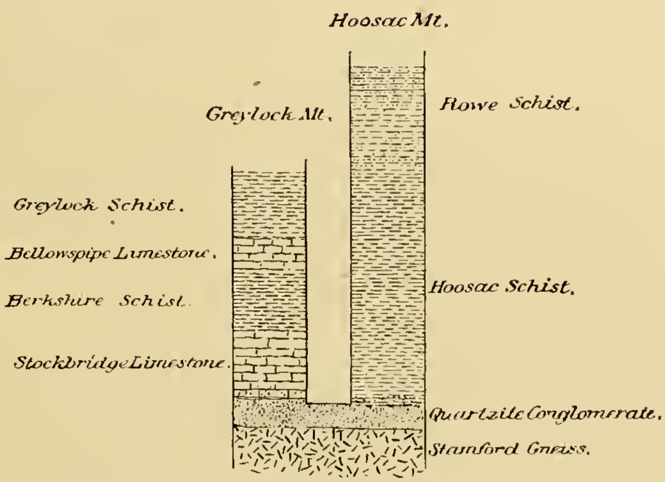


FIG. 3.—Correlated columns of the Hoosac and Greylock rocks.

We now had both the Hoosac and Greylock columns complete, and both springing from the same conformably underlying Cambrian quartzite (see Fig. 3).

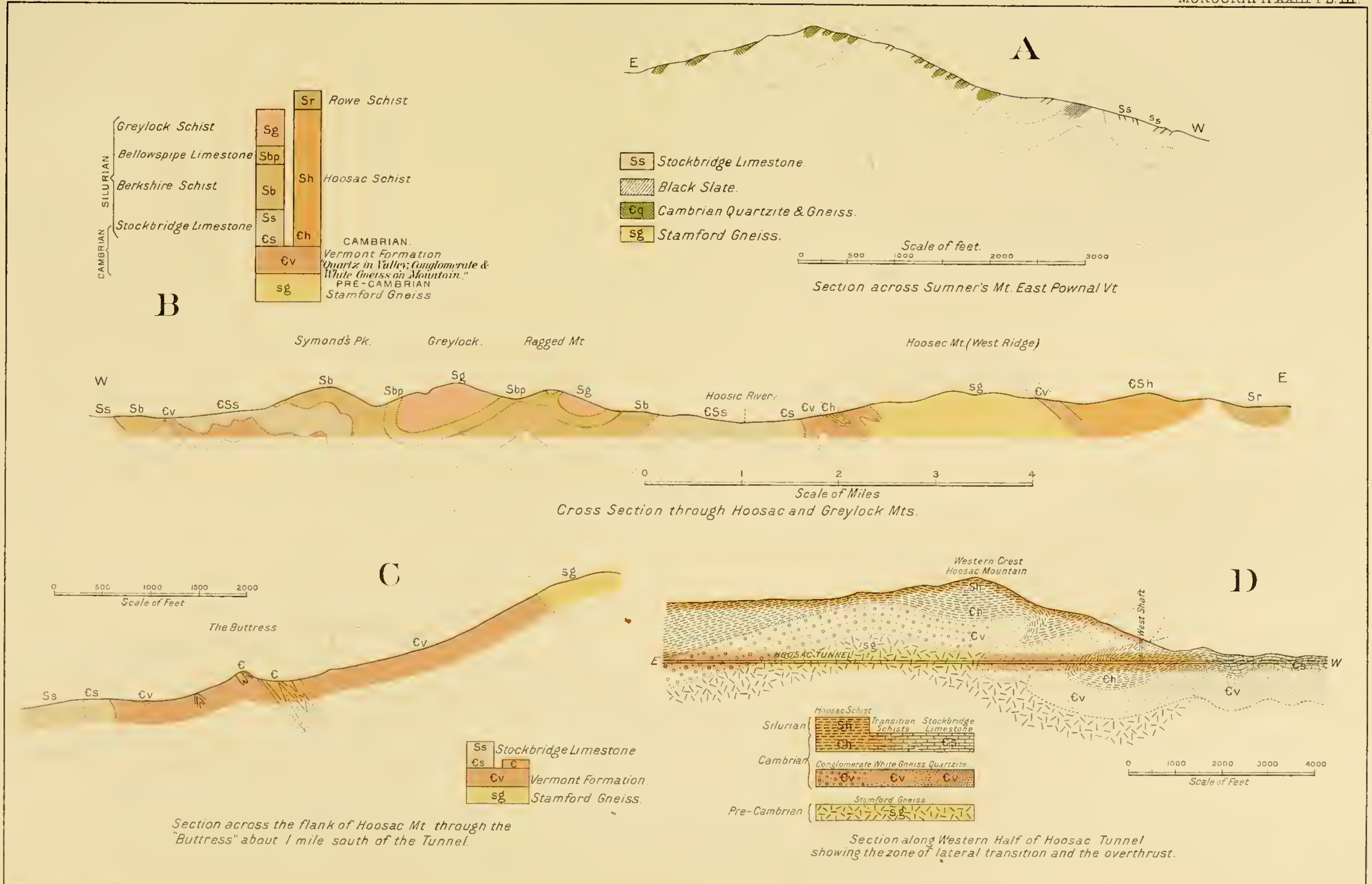
A glance shows one point of difference—the entire absence of limestone in the Hoosac column. But on the other hand, we have the observed continuity of deposition from the quartzite upward in each column, and we have also petrographic identity in the schists of the two columns.

Prof. Emmons attempted to explain the similarity of the Greylock schists to those of Hoosac mountain by deriving the supposedly younger Greylock beds from the destruction of the supposedly older Hoosac rocks, but Mr. Wolff finds, under the microscope, not only no evidence to support the idea of such derivation for the Greylock schists, but that the principal constituent minerals of these schists were in each column all crystallized in place. Early in the course of the work it was proved that the limestone was not present as such in the Hoosac column. But at two points near Cheshire harbor, and east of North Adams, we found schist outliers extending out from the Hoosac column, and at the extreme western ends conformably related to the great limestone; in one case occupying a synclinal trough in it, and in the other either capping it or interbedded in it.

Almost at the beginning of the survey, although we had as yet none of the proofs above given as to the equivalence of the valley quartzite with the Hoosac conglomerate and white gneiss, the strong possibility that at least a part of the Greylock column was contemporaneous with a part of the Hoosac column had presented itself to me. This possibility was strengthened when we had correlated the quartzite with the white gneiss and conglomerate beds as equivalents. The truth of this hypothesis could be tested only by finding beds showing lateral transition to bridge the narrow belt between the Stockbridge limestone and the Hoosac schist.

In the progress of our survey we found, at various points between the valley and the mountain, and always east of the limestone, outcrops of a peculiar rotten schist—quartz and mica with some feldspar, with the mica arranged in long narrow flakes and with sufficient calcite to show the cause of the decomposition. The occurrence of this peculiar calcareous rock along the boundary between limestone and quartzite, as on Tophet creek and below the albitic schist in the western end of the tunnel, shows that it belongs in the horizon of the vertical transition between the quartzite and the limestone, and it seems to represent also the lateral transition zone in this horizon between the Hoosac and Greylock columns.

East of North Adams, on the road to Briggsville, the river cuts longitu-


A
E
W
Ss
Ss Stockbridge Limestone.
Black Slate.
Єq Cambrian Quartzite & Gneiss.
sg Stamford Gneiss.
Scale of feet.
0 500 1000 2000 3000
Section across Sumner's Mt. East Pownal Vt
B
SILURIAN
Greylock Schist
Bellowspipe Limestone
Berkshire Schist
CAMBRIAN
Stockbridge Limestone
Sg
Sbp
Sb
Ss
Єs
Sr Rowe Schist
Sh Hoosac Schist
Єh
CAMBRIAN.
Єv Vermont Formation
"Quartz in Valley; Conglomerate & White Gneiss on Mountain."
PRE-CAMBRIAN
sg Stamford Gneiss
Symond's Pk.
Greylock.
Ragged Mt
Hoosec Mt.(West Ridge)
W
E
Ss Sb Єv ЄSs Sb Sbp Sg Sbp Sg Sb
Hoosic River.
ЄSs Єs Єv Єh Sg Єv ЄSh Sr
0 1 2 3 4
Scale of Miles
Cross Section through Hoosac and Greylock Mts.
C
0 500 1000 1500 2000
Scale of Feet
The Buttress
Ss Єs Єv Є Є Єv sg
Ss Єs Stockbridge Limestone
Є
Єv Vermont Formation.
sg Stamford Gneiss.
Section across the flank of Hoosac Mt through the "Buttress" about 1 mile south of the Tunnel.
D
Western Crest
Hoosac Mountain
Sh Єh Єv sg
E
HOOSAC TUNNEL
West Shaft
Єh Єv Єv Єs W
Hoosac Schist
Silurian
Transition Schists
Stockbridge Limestone
Cambrian
Conglomerate White Gneiss Quartzite
Єv Єv Єv
Stamford Gneiss
Pre-Cambrian
sg
0 1000 2000 3000 4000
Scale of Feet
Section along Western Half of Hoosac Tunnel showing the zone of lateral transition and the overthrust.

dinally through an anticline; a few hundred feet west of the river there is a massive anticline of marble exposed in large quarries; the eastern end dips toward the river, but a sharp anticlinal fold, slightly overturned to the west, brings the strata, up near the west bank of the stream, in interstratified beds of limestone and schist. The arch springs over the river, and its easterly dipping limb forms a high cliff on the eastern bank. In this eastern limb the limestone is represented by calcareous siliceous-micaceous schists and very impure limestones. The whole arch is exposed near by, in a cliff in the bend of the river (see Fig. 4).

This is the most eastern exposure of limestone, and there can be no doubt that we are here in the zone of lateral transition between the conditions that produced in the same horizon the Stockbridge limestone and part of the Hoosac schist. Again, along the north base of the Dalton hills, in

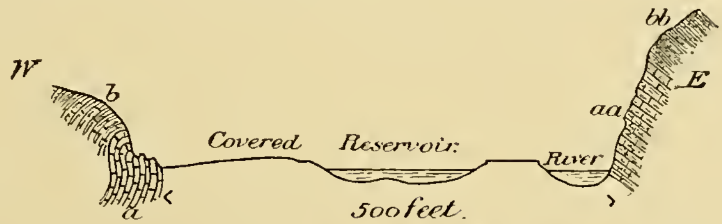


Fig. 4.—Anticlinal arch across Hoosic river between North Adams and Briggsville, in the zone of lateral transition between Stockbridge limestone and Hoosac schist; *a*, limestone more or less micaceous and siliceous; *b*, calcareous and siliceous schist with thin layers of limestone; *aa*, interstratified siliceous and micaceous limestone, calcareous quartzite and mica-schist; *bb*, less calcareous garnetiferous schist.

Cheshire, Mr. Wolff found a schist consisting of calcite, mica, quartz and simple twinned albite, which, from its position and nature, undoubtedly represents this zone of lateral transition from limestone to schist.

If the reader will turn to Plate II he will see that the Stockbridge limestone sends a broad rectangular bay southeast in Cheshire to conform to the embayed topography of the Dalton-Windsor hills. In the middle of this embayment he will observe a detached area of Berkshire schist of an irregular shape, suggesting a long-eared rabbit. There is no question as to the continuity of the schist over the area as represented. The long rabbit-ear-like area lies upon the limestone in a synclinal trough. The structure of this area is not simple; it is that of a small synclinorium, the axes of the north-south running folds pitching toward the center, and the folds at the northern end being more or less overturned to the west in conformity with the general overfolding of Hoosac mountain and the Dalton-Windsor hills. The limestone proper borders the whole western side of the area and extends well into the bay east of Cheshire. On the east side it also extends visibly down from the north for some distance, but it then disappears under a heavily drift-covered area. Going south from the limestone on this east side, the first exposures we find belong to a continuous belt of the schists connecting the Cheshire schist area with the tongue of schist infolded in the Cambrian white gneiss farther east at the base of Hoosac mountain. There is neither any trace of the limestone nor any room for it.

On the south of the Cheshire schist area the Cambrian quartzite covers the Dalton-Windsor hills, the topography of which is formed by the undulations and intervening sharp folds of this hard mantle. The dip of the undulating quartzite beds and the pitch of their sharp folds are both toward the center of the Cheshire schist synclinorium.

The Cheshire schist hills are separated from the higher Dalton-Windsor quartzite hills by a narrow valley, which curves around the southern end of the former with few exposures. But at one point quartzite and schist are very near together, and it is evident that there is no room for the limestone as such. In this valley there are large numbers of great angular blocks and at least one ledge belonging to a transitional schist formation. I repeat here Dr. Wolff's description of this important rock:

It resembles a micaceous white limestone filled with little dark grains or imperfect crystals of feldspar. Under the miscroscope, in thin section, it is composed of a mass of calcite grains, with here and there single grains of quartz, or an aggregate of several grains, plates of muscovite and often of chlorite and biotite, and large porphyritic feldspar grains in single crystals or simple twins, very rarely showing polysynthetic twinning. These feldspars contain inclusions of mica, quartz, iron ore, rutile, and calcite, and are in every way identical with the albites of the albitic schists, although the exact species of plagioclase has not been determined. The calcite seems to play the part which the quartz does in the schists: it sends tongues into the feldspars or cuts them in two, and gives one the impression by its inclusions in the feldspar, and its occurrence with the quartz and mica, that it is of contemporaneous origin with the feldspar, mica, and quartz.

This schist represents the landward transition of the Stockbridge limestone into the Hoosac albitic schist. Thus the Cheshire schist area is at its northern end simply the Berkshire schist resting upon the Stockbridge limestone, while as we go southward we find it representing not only the Berkshire schist, but also the whole thickness of the limestone itself, and as we go eastward we find through continuous exposures its connection and identity with the tongues of schist infolded in the Cambrian quartzite gneiss of Hoosac mountain.

In Fig. 5 I have attempted to represent, in a somewhat ideal section, the transition from limestone to schist at the south end of the Cheshire hill. The transition is clearly quite abrupt, and might easily occur within the space represented by the eroded folded arch between the limestone and the infolded schist along the west base of Hoosac mountain. See C, Pl. III.

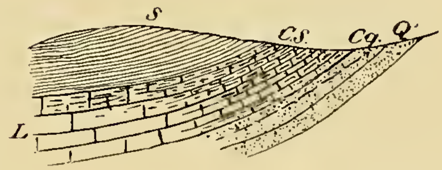


FIG. 5.—Ideal section east of Cheshire, showing lateral transition of limestone to Hoosac schist; *S*, Berkshire schist; *L*, Stockbridge limestone; *Q*, Lower Cambrian quartzite of Dalton-Windsor hills; *Cq*, calcareous quartzite: transition quartzite to limestone; *CS*, calcareous feldspathic schist in lateral transition from Stockbridge limestone to Hoosac schist.

The western end of the Hoosac tunnel lies in the belt of this lateral transition of the Stockbridge limestone into the Hoosac schists; but it is now completely hidden by the brick arching rendered necessary by the decomposed condition of the material. Indeed, it acted for several hundred yards from the portal as a quicksand, and the tunneling work had to be preceded by small tunnels incased in closely matched planks, so fluid was the decomposed water-saturated rock. I have attempted to represent the structural facts at this point on the west flank of Hoosac mountain in D, Pl. III.

At the time of my examination of the tunnel, in 1865, the limestone was exposed in open cuts and tunnels—nearly parallel to the present open cut—for nearly 700 feet east and west. The exposure showed in this distance two rather flat anticlines. The eastern limb of the easternmost anticline dipped east and was for a short distance concealed by masonry. East of this was an open cut, for nearly 400 feet, in the decomposed rotten schist, which seemed to show faintly preserved indications of an easterly dip. Just east of the middle of the cut a less altered bed showed a well-defined syncline with an anticline on the east and having the eastern limb of the latter exposed in the heading with easterly dipping structure.

From the above description it will be seen that the actual nature of the relation of the limestone to the rotten schist was hidden. But just west of where the contact should be I found the limestone conformably overlain by a few feet of Hoosac schist. Farther east is a small shaft, from which was hoisted some of the rock excavated between the western headings of the "west" shaft and the open cut; this rock is a more or less rotten calcareous feldspathic mica-schist, having the same elongated structure parallel to the axes of the folds as in the rotten transition schists of this zone, and marked by the same similarly arranged long, narrow flakes of mica. It recalls in structure, also, at once, the calcareous gneiss associated with the limestone on its eastern border near South Adams, and also the noncalcareous and rather less feldspathic mica-schist of the "Buttress" core. I think that, taken in connection with the facts observed south and east of Cheshire hill, we have in this rock the upward transition from the quartzite to the limestone brought to the tunnel line in an anticlinal arch, and that we have, in the wholly decomposed material of the former open cut, the lateral transition from the rest of the limestone into the Hoosac schist. A few hundred feet, from east to west, would span the whole lateral passage from limestone to Hoosac schist. This transitional calcareous schist decomposes much more easily than the limestone and is therefore more rarely seen. Nevertheless, as stated above, it is found exactly where it should occur as such a transitional form, not only in the western end of the great tunnel, but at several points along the western base of Hoosac mountain above the quartzite and west of the infolded schists.

While the rocks of the zone of lateral transition, in the horizon of vertical transition from quartzite to limestone, were tolerably hard, they succumbed to disintegrating agents much quicker than the quartzite proper. But the rocks of the zone of lateral transition between the limestone and Hoosac schist, being calcareous schists, were adapted to the most rapid destruction, and we therefore find them only where the conditions for their preservation have been exceptional.

From Cheshire hill northward this zone covered anticlinal folds turned over to the west, which have been to a great extent eroded down to the harder beds towards the true quartzite. It does not seem improbable that the zone of lateral transition of limestone to Hoosac schist was a zone of weakness which had much to do with the overfolding along the west base of Hoosac mountain. These anticlinal axes are inclined gently to the north. About a mile south of the tunnel, at the "Buttress," the core of one is visible as a hard, white gneiss, but at the tunnel line it has sunken to where the erosion surface cuts the beds representing the lateral transition of limestone to schist, where they mantle around the pitching anticline, and before they disappear under the younger schist beds which stretch out from the mountain.

While the equivalence of the Greylock column with a large part of the Hoosac column can be thus asserted, I am not yet in a position to make a correlation reaching into details. It is not possible with our present data to subdivide the Hoosac column into equivalents of the two schists and two limestone horizons of Greylock. There is, indeed, in the eastern half of the Hoosac mountains a rather sharply defined plane of division, separating the feldspathic schist on the west from the practically nonfeldspathic schists on the east, and these latter are distinguished further by the fact that their quartz is distributed in thin, even layers, instead of occupying lenses, as in the rocks to the west. This plane is used by Prof. Emerson as the base of his lower hydromica-schist, and forms an important horizon of reference in his work east of the mountain. The thickness of the albitic schists between this plane and the conglomerate has not yet been determined, as the structure is masked by the cleavage. It is certainly not more than 5,600 feet, and probably not less than 2,500 feet. If there are no faults or foldings, it is probably about 4,000 feet. We are equally ignorant of the real thickness of the Greylock beds, after allowing for the effect of lateral pressure and increasing local thickness. But it is quite possible, if not probable, that these nonfeldspathic schists belong wholly above the Greylock rocks. In the study of Greylock mountain Mr. Dale, by patient search for the traces of the original stratification, which have here and there escaped the general obliteration caused by cleavage, has been able to work out the details of surface structure quite closely, and to obtain a general idea at least as to the maximum thickness of the two limestones and two schists. But the compressed foldings have so altered the thickness of the strata that it is impossible to give the real vertical dimensions. His estimate is:

Greylock schist	1,500–2,000
Bellowspipe limestone	600– 700
Berkshire schist	1,000–2,000
Stockbridge limestone	1,200–1,400

These are, however, based on measurements of beds that have been subjected to strong lateral compression, and, as Mr. Dale observes, although the aggregate maximum of the thickness given above is below that assigned to the Lower Silurian in the Appalachian region, it is probably far in excess of the real thickness, which may be considerably below the maximum above given.

The sediments which in vast thickness form the substance of the Green mountain system have been subjected to intense lateral thrust, which has produced numerous folds. These, as a rule, are more or less compressed and overturned to the west, in places indeed forced over until the axial plane lies almost horizontally, or compensations have taken place through overfaulting. The sections and map of the Hoosac-Greylock region illustrate the structure in its generality.

From these it will be seen that on Hoosac mountain the granitoid gneiss and the overlying conglomerate gneiss-quartzite and albitic schists have been folded into a low anticlinal arch, the western side of which has been forced over to form an overfold to the west.

An examination of the longitudinal sections on Plate VI accompanying Part II (Mr. Wolff's report) shows that the southern end of this arch is overfolded in the same manner, but to the south. We have thus the remarkable occurrence of an overturned anticline abruptly turning a right angle. A glance at the map (Plate II) will show that this is repeated by the next overfolded anticline to the west, which bends equally abruptly around to run eastward, and that the inverted trough between these anticlines is still marked by the infolded band of schist. Going from this southward, we come immediately upon another east and west trough of schist, also overturned to the south. Still further southwest, we find along the northern part of the Dalton-Windsor hills the quartzite gneiss beds thrown into overfolds, but with the axes striking northwest to southeast; while still farther westward they are overfolded to the west, but with the axes in the normal position of the Green mountain folds—nearly north and south.

Looking at the map and sections of Greylock, Pls. I, XVIII, XXIII, we find a great basin-bottomed mass, thrown into numerous more or less overturned folds, with axes in the normal Green mountain position, and inclined from each end toward the middle. Again, if we look at the eastern border of the map, we find in the observed strikes and dips of the conglomerate gneiss and schist east of the granitoid, no trace of a departure from the general Green mountain direction.

This local modification in the structure of Hoosac mountain must be due to some local cause, which I think must be sought in the pre-Cambrian topography. The Greylock basin of sediment was guarded on the north by the large mass of granitoid gneiss of Clarksburg mountain, and on the south by the great body of pre-Cambrian rocks which are now masked by the Dalton and Windsor quartzite. I imagine that the lateral thrust to which the foldings are due met with greater resistance opposite these more rigid granitic masses than in the interval, and that the abnormal overfoldings to the south, described above, are the result of compensatory movement. The Hoosac mountain cross sections show a much more marked overturn than is observed to either the east or west of it. The axial plane of the principal overturned fold on the west side of the mountain lies very flat. We may suppose the greater rigidity of the granitoid gneiss to have caused it to yield as a unit to the contracting force. Only its relatively narrow top participated in the actual folding and was carried over to form, with the leeward, protected beds, a flat-lying, compressed syncline.

A similar overturn, though not so flat, was observed by us on Sumner mountain, in Pownal, on the west of the Clarksburg mass of granitoid gneiss. Section A on Plate III was made by Mr. B. T. Putnam. I have added my interpretation in dotted lines. This outlier is separated from Clarksburg mountain by Broad brook, this interval being occupied by the quartzite. The large Clarksburg mass of granitoid gneiss remained a dome mantled by the Cambrian quartzite, and showing the effect of the folding force only in the induced lamination common to itself and the quartzite, while in the smaller mountain to the west, which has a granitoid gneiss core, this core is pushed up in the form of an overturned anticline upon which the quartzite lies, in normal position on the east, while on the west the granitoid is underlain, in inverted order, by the quartzite and the limestone.

A careful study of the western flank of Hoosac mountain shows that its structure is not that of a simple, great, overturned fold. It consists of a series of parallel, crumpled folds, one or more of which have a greater depth than the others. All of them are overfolded, with their axial planes dipping eastward and with their axes pitching about 10° northward. The average chord-plane of these folds dips westward 15° to 20°, forming thus, as a whole, a comparatively flat, though much crumpled, western limb of

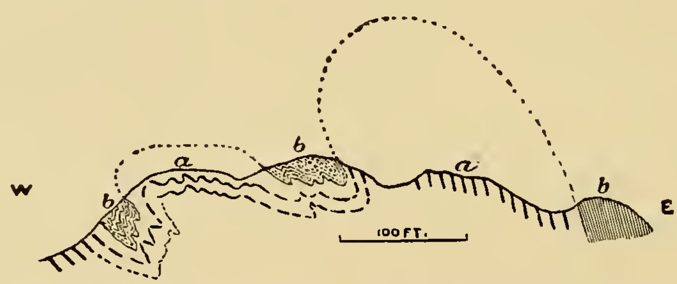


FIG. 6.—Diagram of structure, summit of the Buttress, on west flank of Hoosac mountain, about one mile south of Hoosac tunnel. *a*, Buttress rock, upper part of Cambrian white gneiss; *b*, Hoosac schist. The exposure at the east end is part of the long trough infolded along the whole front of Hoosac mountain.

the main Green mountain anticlinal arch. This structure is shown in numerous preserved fold-cores, and is illustrated in the section through the "Buttress" (Plate III, C) and in the annexed diagram of the summit of the same hill (Fig. 6). The "Buttress"—a high hill on the flank of the mountain about one mile south of the tunnel—is the southerly extension of one of the larger of these crumples, where the axis in rising to the south brings up the harder core of Cambrian white gneiss. The structure is marked both by the preserved fold-core at *a*, just west of the summit (Fig. 6), and by the small infolded troughs of younger schist at *b* on the summit and *b* on the western flank. Further north, as at the tunnel line, where nearly the whole flank of the mountain is covered by the schist, the crumpling is much greater, as one would expect in this material, and is marked by the crumpled layers of quartz (Fig. 7). Toward the south end of the mountain, near where the great schist trough is seen on the map to turn sharply to the east, the evidence of this same structure is preserved in several minor infoldings of schist.

In the tunnel the rotten rock of the old open cut, and that which I have described as the Buttress-core rock and as forming below it the upward transition from quartzite horizon to limestone horizon, are concealed by masonry. But from a point several hundred feet west of the "west" shaft we find the Hoosac albitic schist, which extends some 1,400 or 1,500 feet further east till we reach its contact with the underlying conglomerate-white-gneiss (See Pl. III, D). This last-mentioned rock extends some 2,000 feet farther east to its contact with the pre-Cambrian coarse crystalline gneiss of the Hoosac core. On both its eastern and western sides

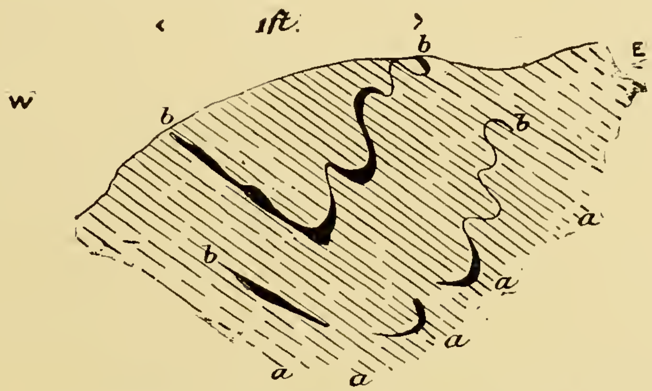


FIG. 7.—Crumpled structure in the Hoosac schist above the "west shaft" on Hoosac mountain. *a*, cleavage foliation; *b*, stratification lines marked by crumpled quartz layers.

the contact planes show that the Cambrian white gneiss is overturned in a flat-lying anticline. Leaving, now, the tunnel and climbing to the opening of the "west" shaft on the flank of the mountain we find that the upper part of the shaft is in the Buttress-core rock—quartzite-limestone transition rock—and that the same formation crops out upon the mountain until we reach the Hoosac schists, several hundred feet higher up. Climbing above this point we find the Hoosac schists, with evidence that they occupy an inverted syncline. Fig. 7 shows the structure at this point on a small scale. Above this the dips observed on both sides of the summit show that the crest is a simple open syncline.

The presence of the Buttress-core rock at the top of the "west" shaft and its projection so far westward over the Hoosac schist of the tunnel below can be explained only by introducing an overthrust fault or by supposing that the inverted anticline was pushed out thus far without rupture. The former explanation seems the more likely one and accords better with the thickness of the Cambrian gneiss and the dips in the schist observed in the tunnel. The bed of white gneiss—600 to 800 feet thick—when exposed to the great thrust which overfolded the Hoosac rocks, would, it seems, be less able to adapt itself by minor foldings than the more readily yielding schist, and would be more likely to find its compensation in a rupture and an overthrust fault.

At the tunnel line the axes of the folds are still pitching to the north. Immediately north of the limestone is a mass of folded Hoosac schist, under which the limestone is carried by the pitch of its folds and which is seen at several points to be younger than the limestone. The zone of lateral transition is also carried under this hill, and this fact explains the peculiar areal geology of this part of the map (Pl. I) on which the color for the Stockbridge limestone extends along the west side of the schist hill, that for the Vermont formation along the east side. The obscurity disappears on Pl. II, where I have separated these transitional rocks from the quartzite and given to them and to the lower part of the limestone a separate representation as Cambrian.

It is not easy to determine the extent to which overthrust faulting has entered into the building of the Green mountain range in northwestern Massachusetts. Along the eastern side of the pre-Cambrian core of Hoosac mountain the movement flattened the coarse pebbles of the conglomerate and granulated their quartz and large feldspars to the point of obliteration. But the great Cambrian conglomerate-gneiss bed as it curves around the core shows no break due to faulting. It is not until we come to the west side of the pre-Cambrian gneiss-core that we find evidence of a rupture in the flat fold, where the hard Cambrian white gneiss has been pushed along an overthrust fault onto the younger schists as far as the west shaft. Here it seems probable that the rupture was favored by the fact that the troughs of the folds, both above and below the middle limb, were on the lee side of the less yielding pre-Cambrian core, as will be seen from the section (Pl III, D). Now this is the same fold that incloses the trough of schist all along the west side and south end of the mountain, and it is not impossible that it may be accompanied there, as here, by the same rupture. If this is so, then the position of this overthrust plane would lie above and to the east of the schist trough shown on the Buttress (Pl. III, C, D).

Having sketched thus briefly the general relation of the crystalline schists of the main ridge of the Green mountains to the fossiliferous rocks lying to the west, let us now return to the main ridge.

We have seen that the Cambrian white gneiss rests with a time break on the coarse granitoid gneiss In places on Clarksburg mountain we find the micaceous quartzite more or less conglomeratic at the base, resting on the granitoid gneiss, the two rocks sharply distinct. In others, as on Hoosac mountain, a conglomerate rests on the granitoid gneiss with sharp definition. But this simplicity is not always present, especially at the meeting of the white and granitoid gneisses. In general there intervenes between the well-defined coarse gneiss and the well-marked white gneiss a zone of beds of more or less coarse gneiss, often alternating with finer grained biotite schists. It is not easy in such places to draw the line between the Cambrian and pre-Cambrian formations, though, as I will show further on, in some instances there is good reason to draw the line at the base of the transitional beds where these show alternating strata of varying character. One thing appears certain: the dynamic action which has folded these rocks has impressed upon them not only their cleavage and plication, but also the remarkable simulation of conformity in bedding and of vertical transition.

The pre-Cambrian core of the Green mountains reappears at frequent points along the range. In places it forms almost island-like masses of old, hard gneisses surrounded by the Cambrian quartzites and allied rocks, as in the northwestern corner of Connecticut. In others, as on Hoosac and Clarksburg mountains, it appears as limited, oval, dome-like areas of granitoid gneiss. Again, as in Chittenden, Vermont, it consists of a long, narrow line of coarse gneiss, at eroded points in the backbone of the range. Finally, as between Clarendon and Ludlow, in Vermont, where the height of the range has been cut down by the removal of the younger rocks, the core of the folded range shows itself in a variety of old granitic and gneissoid rocks, cut by intrusives and with extremely irregular structure

We have done but little work towards the study of this old core. A valuable clew was found by Prof. Emerson in what he considers to be a threefold division of the pre-Cambrian in southern Berkshire, where, according to his observations, chondroditic limestone separates a coarse, blue quartz gneiss—possibly the Stamford granitoid—from a still older gneiss.

The massive granitoid gneiss which forms the core on Hoosac and Clarksburg mountains is in places separated from the overlying Cambrian quartzite gneiss series by beds of coarse, light-colored gneisses, which have interbedded layers of finer grain and darker color from the greater proportion of biotite. These "transitional coarse gneisses" between the granitoid and white gneisses are probably, to a great extent at least, Cambrian. They are detrital, containing pebbles in places, as in the tunnel. Their coarse feldspar is identical with that of the granitoid gneiss, except that in this transitional zone it is white, while in the granitoid it is reddish. While the granitoid gneiss is preeminently a massive rock, this "transitional" zone is bedded and contains micaceous layers. On the east side of the granitoid area on the surface of Hoosac mountain it occupies the place of the quartzite-white-gneiss-conglomerate and is overlaid conformably (as seen at the contact) by the albite-schists. The granitoid gneiss was probably much disintegrated at the time of the Cambrian transgression, and in the different conditions of character of disintegrated material and of breaching and sedimentation lies, perhaps, to a considerable extent, the explanation of the fact that this horizon is here quartzite and there gneiss, and presents itself under a great variety of aspects, due to alternating layers with varying proportions of quartz, feldspar, and mica. But in the field it is often very difficult to distinguish, in the absence of true pebbles and of alternating sediments, between the redeposited detritus of disintegration, which has been subjected to the action of chemical and dynamic metamorphism, on the one hand, and beds which, simulating these, have been produced by the action of these same metamorphic agencies directly upon the older gneisses, granites, or basic eruptives.

I imagine that the Cambrian transgression found an Archean elevation forming the western border of an Archean dry region. To the west of this lay the great Paleozoic ocean of America. I imagine, also, that the rocks of this dry area had become disintegrated to a greater or less depth and that the products of this action varied from kaolin and quartz at the surface to semikaolinized material with fresh cores at depths. The depth of this action would vary according to varying lithologic and topographic conditions, as I have shown elsewhere.[1]

While the abrasion of the deeply disintegrated rock was progressing along the advancing beach line the detritus of sand and pebbles arising from this disintegrated material was deposited with varying proportions of its constituents in a continuous sheet in progressive "transgression" over the previously dry land;[2] for I think the evidence offered by the erosion of the Stamford dike is sufficient to show that the region owed its absence of older sediments to its having been an area of dry land instead of an "abyssal" area.

During the progress of this removal and deposition of ready-prepared material there would be places where the underlying unaltered rock would be washed clean and re-covered with sand and gravel. There would be others where the material removed from the disintegrated mass would be derived from the zone of semikaolinized fragmentary disintegration, and places where this material would be deposited without having been much rolled and in beds alternating with finer material. And again there would be places where the disintegration was deeper—in basins as it were—and where this material escaped removal and was covered by the sedimentary beds. The recognition of these premises would, it seems to me, aid in the explanation of many of the difficult points observed in the field.

Take, for instance, the schistose lamination of the Stamford gneiss on Clarksburg mountain, where this structure is most highly marked near the contact with the overlying quartzite. The lamination is parallel in both rocks. The quartzite here bends around the mountain and is highly crinkled, this structure being defined by the micaceous constituent, and for some distance

[1] Secular rock disintegration, etc. Am. Jour. Sci., vol. 17, 1879, pp. 133-144. Also the application and extension of the ideas advanced in that paper. F. von Richthofen: China, vol. 2, p. 758.

[2] F. von Richthofen has called attention to the fact that too little importance has been attached by geologists as a rule to the breaching and abrading action of the ocean when the beach line is advancing landward. China, vol. 2, p. 768.

inward the same structure is similarly defined in the granitoid gneiss and is perfectly conformable in the two rocks, although we have here, in the conglomeratic character of the base of the quartzite and in the pre-Cambrian erosion of the Stamford dike, evidence of a time-break. If we imagine the granitoid gneiss to have been deeply disintegrated and to have been abraded only to the semidisintegrated zone, or even to the lower zone in which only the integrity of the micaceous element had been attacked, then the material of this zone would have presented itself to the force that produced the crinkling and lamination in much the same physical condition as the sand and pebbles of the quartzite.

Again, take the coarse gneisses with blue quartz which occur at many points along the core. Mr. Wolff finds them to contain the same feldspar with the same inclusions as that of the granitoid gneiss, except that they are light colored, while those of the granitoid are reddish, and they have frequently the same blue quartz. But they are bedded and have alternating layers of finer schists, and appear as transitions conformable to the underlying granitoid and overlying white gneiss or other equivalents of the Cambrian quartzite. The granitoid gneiss consists of large crystals of feldspar—perhaps averaging one by three-quarters by one-third inch in size—and flattened lenses of blue quartz and thin, irregular layers of mica. I imagine that these materials, taken from the zone of semidisintegration and quickly deposited, would, in their new arrangement, produce our "transitional coarse gneisses," while the material of the upper zone of complete decay would furnish the sand and clay for the quartzite and finer sediments.

If this reasoning be correct, we should in many instances include in the Cambrian quartzite series the coarse, more thinly bedded gneisses, with their interbedded, finer grained schists. But in the present state of our knowledge of the Green mountains the granitoid gneiss appears to be only one of the constituents of the old core, and perhaps a subordinate one. From our recent work in Vermont it seems that the pre-Cambrian area will be found to contain a variety of granites, gneisses, and schists, as well as basic rocks, which will need to be studied in connection with the rocks of both the New York highlands and the Adirondacks. It therefore remains to be discovered whether the old core contains any rocks of the periods between the Archean (Laurentian) and Cambrian. Thus far only some observations that will serve as clews have been made in this direction.[1] One apparently negative piece of evidence may be seen at the place where the Archean rocks of the New York highlands suddenly end near Poughquag, Dutchess county, New York. Here the highlands end in a promontory of nearly vertical beds of old gneisses, against which the Cambrian quartzite lies with a very flat dip.

Toward the correlation of the Green mountain rocks with the fossiliferous strata of New York, the paleontologists have given us some facts. Mr. Walcott's discovery of Olenellus casts in the quartzite of Clarksburg mountain, about 100 feet above its base, caused him to assign that rock to the Lower Cambrian. The many findings of Lower Silurian fossils in the limestone of Vermont have shown that limestone to include Calciferous, Chazy, and Trenton horizons, and it is inferred that, since the limestone is Trenton and is capped by schists, the latter are of the age of the Utica and Hudson River slates.

I have shown above that the white gneisses and conglomerates of Hoosac mountain are the equivalents of the Cambrian quartzite and that the albitic schists of Hoosac mountain represent in time both the limestone and schists of the valley, and therefore range from the Cambrian into or through the Hudson River.

It seems probable that the limestone must reach down well into the Cambrian and that all of the Cambrian that is not represented by the quartzite must, in the valley, be included in the lower part of the limestone and its downward transition beds;[2] while on the mountain it must be included in the lower beds of the albite schists.

We have yet to discover whether the nonfeldspathic schist of the eastern portal of the tunnel (Rowe schist) represents Hudson River, or, perhaps, Medina time. Geologically above the nonfeldspathic schists of the eastern portal, and coming in successively to the east to build up the old plateau region that forms properly the eastern belt of the Green moun-

[1] Since this was written we have found Algonkian schists at several points along the Green mountains.

[2] This has been confirmed by recent discoveries of Cambrian fossils in the lower part of the limestone near Rutland and Clarendon, Vermont, by Messrs. Foerste, Wolff, and Dale.

tain system as far as the Connecticut valley, there is a series of schists having a great aggregate thickness. Prof. Emerson, to whose report the reader is referred for the descriptions and for the views of our predecessors, has been able to divide these schists into several distinct formations with persistently defined characters and boundaries. Above the nonfeldspathic Rowe schists comes a horizon of hornblende schist (Chester amphibolite) often with serpentine, varying from a feather edge to 3,000 feet in thickness, overlain by over 9,000 feet of "upper hydromica-schist" (Plainfield schist). This in turn is overlain by the "Calciferous mica-schist" of the Vermont survey (Conway schist), which obtained its former name from the presence of occasional large lenses of more or less biotitic limestone, which latter has beds of hornblende-feldspar-schist in places along its bottom and top. Above this again is the heavy bed of Leyden argillite, with intercalated quartz-schist. Next above and unconformably superposed are the representatives of the Devonian. The age of these different formations still remains uncertain, though at least the Leyden argillite and the Conway schist ("Calciferous mica-schist") are supposed by Prof. Emerson to belong to the Upper Silurian.

While the Green mountain system includes the whole region between the Connecticut and the Hudson, its characteristic features consist, as we have seen, of the central anticlinal ridge of the Green mountains proper on the east, the synclinal range of the Taconic mountains on the west, and a succession of high, synclinal, island-like masses rising from the intermediate valley. The results of the survey in northwestern Massachusetts lead to the supposition that the central or main ridge was in pre-Cambrian time outlined as a mountain range of highly crystalline rocks on the western border of an area of dry land. During long exposure to the action of atmospheric agencies and of the products of vegetable decay, the rocks of this region had become decomposed at the surface and disintegrated at depths.

The breaching action along the advancing shore line of the Cambrian sea found ready prepared the materials which the water assorted and distributed to form the great sheet of Cambrian rocks. While these deposits of detritus were accumulating over the shallow areas, the materials for the future limestone were gathering offshore to the west. As the positive movement deepened the water shoreward, the calcareous materials accumulated above the earlier detrital beds, so that we may imagine that, while the later beds of the Cambrian were being made of sand and gravel in shallow water, the lower beds of the great limestone formation were being deposited offshore. Later, with a change of some kind in the conditions, there came the deposit of finer material over the previously shallow region, while the accumulation of limestone, with Lower Silurian organisms, still continued offshore. Still later, by another change in the conditions, the deposit of finer detrital material extended far to seaward, covering everywhere the limestone accumulations.

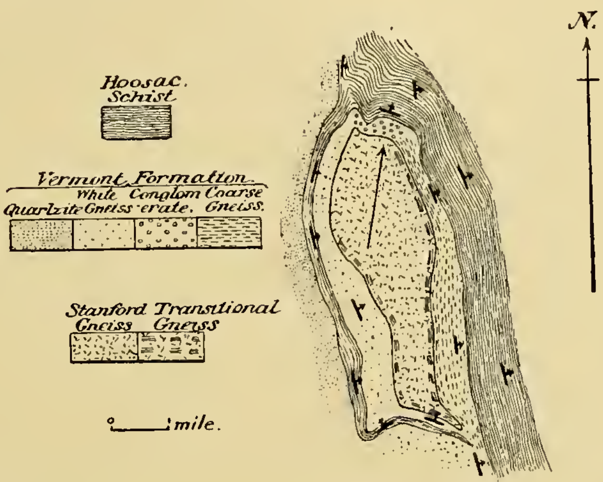


FIG. 8.—Map showing the varying character of the Cambrian rocks in contact with the pre-Cambrian granitoid gneiss mass on Hoosac mountain.

As we are not yet able to say to what depth into the Cambrian the limestone may extend in the Hoosac valley, so, also, we are unable to say to what extent the lower beds of schists on Hoosac mountain may represent Cambrian time.

Mr. Wolff has shown that the Cambrian quartzite horizon, which is a true conglomerate on the top of the arch at the north end of the granitoid gneiss area, consists on the eastern and easterly dipping limb of coarse gneisses, showing only occasional pebbles, as in the tunnel, while on the western and crumpled limb it is represented by finer-grained white gneiss. These relations are shown in Fig. 8. We may suppose an island of coarse granitoid gneiss with a disintegrated mantle, and imagine this latter to have been abraded down to its less disintegrated zone, and the resulting coarser material to have been laid down, during the positive movement, over the gneiss area. In the subsequent folding I imagine that the rigidity of the unaltered granitoid mass offered far greater resistance to the folding than any of the superposed material, and that, as a result of this resisting, inverted wedge, the material of the eastern limb was subjected to the slipping or shearing movement producing the coarse laminated structure of these gneissoid rocks, while the similar material on the west limb, having a more rigid base which yielded less readily to overfolding, was forced into minor overfolded crumples and crushed into a finer grain. Beneath the gneisses remade out of the conglomerate by dynamic action during the folding, there would be formed more or less similar transitional rocks through the action of the same dynamic processes upon the semidisintegrated surface of the older rock. This is what is found at many points along this contact in Hoosac mountain.

From what has just been said it is evident that the high degree of metamorphism of the Paleozoic rocks is intimately connected with the folding. It is also a salient fact that, while the schists and limestone are wholly recrystallized throughout the whole folded area beginning west of the Taconic range, the change of the underlying Cambrian quartzite to a crystalline rock—a white gneiss—does not begin until, in going east, we reach the central, main range. In this sense the metamorphism of the schists is regional; that of the quartzite has the appearance of being local.

Both the quartzite and the overlying schists contain tourmaline, crystallized in situ, and frequent lenses or faulted veins of quartz, feldspar, and tourmaline. The schists contain in places needles of rutile. As we follow the quartzite in its transition to white gneiss we find here and there pegmatite veins, more often near its contact with the core of older gneiss.

If we could go back to the original character of the sediments we would find west of the western flank of Hoosac mountain a column of fine sediments, probably argillaceous, with, in places, calcareous bands, resting on a thousand feet or more of limestone, and this on six or eight hundred feet of Lower Cambrian grit—here a quartz sandstone. On the eastern side of the western flank of Hoosac mountain we would find many thousand feet of the same fine sediments resting on, and passing downward into the Cambrian grit—here a coarse conglomerate abounding in detrital feldspar in its cement. We would find the limestone of the western column represented only by more or less calcareous material in the fine sediments of the corresponding part of the eastern column, and by a rather abrupt lateral transition through flaggy limestones and marls, containing more quartz sand at the bottom and more clay at the top. Above this horizon we would find the fine sediments alike common to both columns and extending far both to the east and the west.

Analyzing the different horizons we find along the west side of Hoosac mountain different conditions of sedimentation affecting the horizons of both the grit and the limestone. To the east the grit becomes a conglomerate abounding in granitic pebbles and in detrital feldspar. To the east also the limestone passes into shoreward argillaceous sediments. Higher up we find in the uniformly widespread fine sediments the evidence of changed conditions, which through a long period excluded to a great extent the formation of limestones over the whole region.

Such in a general way was the differentiated character of the rocks upon which the processes of metamorphism acted. These processes resulted in changing the quartz sandstone of the Cambrian grit into a quartzite, and the shoreward feldspathic sandstone into a highly crystalline gneiss. The Cambro-Silurian limestone, the limestone proper, was changed to crystalline limestone; its shoreward transitions into more or less calcareous gneiss and its more eastward calcareous shales into a garnetiferous variety of the albitic schist, into which the whole column of Cambro-Silurian fine sediments above the lower Cambrian grit has been changed. In the finer sediments, the uniform character above the horizon of the limestone resulted in a uniform change into a mica-schist characterized by the general presence of albite in macroscopic or microscopic crystals.

We do not yet know to what depth these rocks were buried. They have in themselves an aggregate thickness of 5,000 feet or more. Certainly if they were covered by the great thickness of material represented in the schists between Hoosac mountain and the Connecticut river, they were buried to a point of load and temperature sufficient to satisfy these conditions of metamorphism.

Throughout the whole region all the rocks above the pre-Cambrian have been subjected to the action of great lateral pressure, throwing them into folds and along certain lines into compressed and ruptured overfolds, subjecting the constituent particles to crushing or shearing and to movements which are now marked by the crinkling of the original stratification lamination, and by the predominant cleavage resulting from movement.

There were therefore present the three factors of load, temperature, and attrition of particle on particle produced during the folding movement. These factors were essential in the process of metamorphism, but they could not change ordinary clay sediments into schists consisting largely of magnesia and potash micas and abounding in soda-feldspars, nor could they change a grit of quartz and microcline detritus into a gneiss consisting largely of soda-feldspar. Either the original sediments must have contained all of the elements required to form by recrystallization the present constituent minerals, or a part must have been contributed from elsewhere. The extreme rarity of observed eruptive dikes and of pegmatite veins outside of limited areas makes it hard to explain the difference between the chemical constitution of the schists in their great breadth and thickness and that of ordinary argillaceous sediments by ascension from below. It would therefore appear more likely that the original sediments were of an exceptional character. They may have been deposited under conditions favorable to the preservation of magnesium and alkaline salts—conditions which we know have at various times existed over large areas.

In the case of the Lower Cambrian grit the action of mineralizing processes originating below is more probable. Where the rocks have been subjected to the different forms of readjustment of particles during the great folding of the strata, a change occurs from a grit containing much detrital microcline to a highly crystalline gneiss with a predominant soda feldspar, which bears evidence of being crystallized in situ. Along these zones we find veins and "flames" of pegmatite, and in the crushed quartzite proper perfect little crystals of tourmaline often appear in great abundance. The very feldspathic veins along these zones of extreme folding in the grit may stand related causally to the lenses of quartz and tourmaline, with and without feldspar, which occur rather frequently in the higher schists along the west flank of Hoosac mountain; also along the zone of extreme folding.

PART II.

THE GEOLOGY OF HOOSAC MOUNTAIN

AND

ADJACENT TERRITORY.

BY

J. E. WOLFF.

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THE GEOLOGY OF HOOSAC MOUNTAIN AND ADJACENT TERRITORY.

By J. E. Wolff.

INTRODUCTION.

The territory embraced in this report extends from the Hoosic valley in the west to the meridian of 73° on the east, and from the state line on the north to the valley in the south which runs east from Pittsfield through Dalton. It covers the easterly half of the "Greylock sheet" of the new map of Massachusetts. It is an area about 18 miles in length, varying from 10 to 4 miles in width, and covering about 120 square miles.

TOPOGRAPHIC WORK.

As the extreme complication of the field required great accuracy in the location of outcrops, at an early stage in the work a base-line 7,000 feet long was measured on the Boston and Albany railroad in Hoosic valley and a sufficient number of points were established by triangulation to allow the accurate vertical and horizontal topographic determination of important outcrops, which were then plotted on a large field map on a scale of 1,000 feet to the inch. Subsequently the plane-table sheets of the state map (scale 2 inches to the mile) were utilized, and a special topographic map of that part of Hoosac mountain near the tunnel (on a scale of 1,000 feet to the inch) was prepared. At many places accurate section lines were run by the stadia and the geological points incorporated in the general map.

TOPOGRAPHY.

Hoosac mountain is the name applied to a part of the Green mountains situated in the northwest corner of the state of Massachusetts, near the Vermont boundary. This region forms the watershed between the Hoosic and

Deerfield rivers, branches of the Hudson and Connecticut, respectively. At its southern end it is drained by branches of the Hoosatonic and by the Westfield river, a branch of the Connecticut.

The entire mountain mass is cut through at its central part from east to west by the Hoosac tunnel, nearly 5 miles long, the tunnel passing almost directly under the highest point of this part of the mountain, a knob one-half mile north of Spruce hill, which is 2,600 feet above the sea. At the extreme north of the field, half a mile south of the Vermont line, the highest point is found to be 2,800 feet. Where the tunnel crosses the central part of the mountain the outline is that of a double crest with a central basin or

Fig. 9.—View looking west from slope of Hoosac mountain, east of North Adams. This gives a general idea of the topography of the valley.

depression (see Profile III, Pl. V), the two sides joining at the north end to form the high north point and to terminate the basin.

In its southern-central portion the mountain loses the north to south ridges and drainage. It is there characterized by flat, rounded summits and gentle depressions, and a frequent east to west trend of the valleys. A glance at the strike and distribution of the formations will show that the frequent east to west strike and extreme crumpling of the white gneisses which occupy this region cause this difference in the topography. In the southern part of the field a north to south strike of considerable regularity again comes in, causing a more ridge-like topography, until the deep east to west valley of Dalton, a mile or so south of the map (Pl. I), bounds the region on the south.

On the east the mountain joins the hilly country extending to the Connecticut river; on the west the broad Hoosic valley, running north and south, bounds Hoosic mountain and separates it from the mass of Greylock mountain, the highest in the state. (See Fig. 9).

The relations of topography to geological structure are often noticeable. The whole eastern border of the area shown on the map is covered

FIG. 10.—Profile of part of west crest of Hoosac mountain, looking east from Hoosic valley opposite Adams. This shows the continued northerly pitch of the axis some miles south of point shown in Pl. XI, B. The summit in the right center is of white gneiss (Vermont formation) with a little indistinct minor ridge of the Hoosac schist trough, both slanting to the left (north).

by the schists, characterized by a uniform north to south strike and steep easterly dip of their structural planes; and the ridge topography, with deep cross-gorges for the streams, is evidently due to that structure.

The long crest of Hoosac mountain, forming the main watershed, coincides in direction and position with the axis of the northerly pitching fold which forms the principal feature of the mountain, and with the axis of the central core of granitoid gneiss. The presence of the limestone in the Hoosic and Dalton valleys determined these depressions, as is always the case with that rock.

The profile of Hoosac mountain shows plainly the northerly "pitch"[1] of the formations by the gentle slopes to the north and the bluffs facing south. (See Fig. 10 and Pl. XI, B.) The western slopes of Hoosac mountain running down to the Hoosic valley are steep, but have a marked series of buttresses or benches. (See Fig. 11.) The drift-covered Hoosic valley is

FIG. 11.—Profile of west slope of Hoosac mountain, from Hoosic valley opposite Adams, looking north.
This figure shows the buttressed character of the west slope of the mountain at the left center. These buttresses are of crumpled white gneiss (Vermont formation), with a gentle easterly dip.

comparatively flat, sending branches into the mountain, which are locally called "coves." At Cheshire the valley makes a sharp turn to the west.

DESCRIPTION OF THE ROCKS OF HOOSAC MOUNTAIN.

The rocks of this region are thoroughly crystalline, but little trace remaining in general of their original elements, whether of detrital or eruptive origin, but the bedding corresponding to the original planes of deposit is well marked, and, under the proper conditions, we can therefore determine the order of succession.

[1] Meaning that the *axes* of the folds are inclined or "plunge" in that direction.

THE STAMFORD GNEISS.

The basement rock is a coarse granitoid gneiss, which forms the core of Hoosac mountain proper, occupying the surface of the mountain for several miles, then disappearing below the overlying rock, but cut in Hoosac tunnel for nearly 5,000 feet; hence this rock figures prominently on the dumps of the tunnel shafts. Another area of the same rock underlies the fossiliferous Cambrian quartzite of Clarksburg mountain, north of Williamstown, continuing some miles northward into Vermont—the "Stamford granite" of the Vermont geological report.

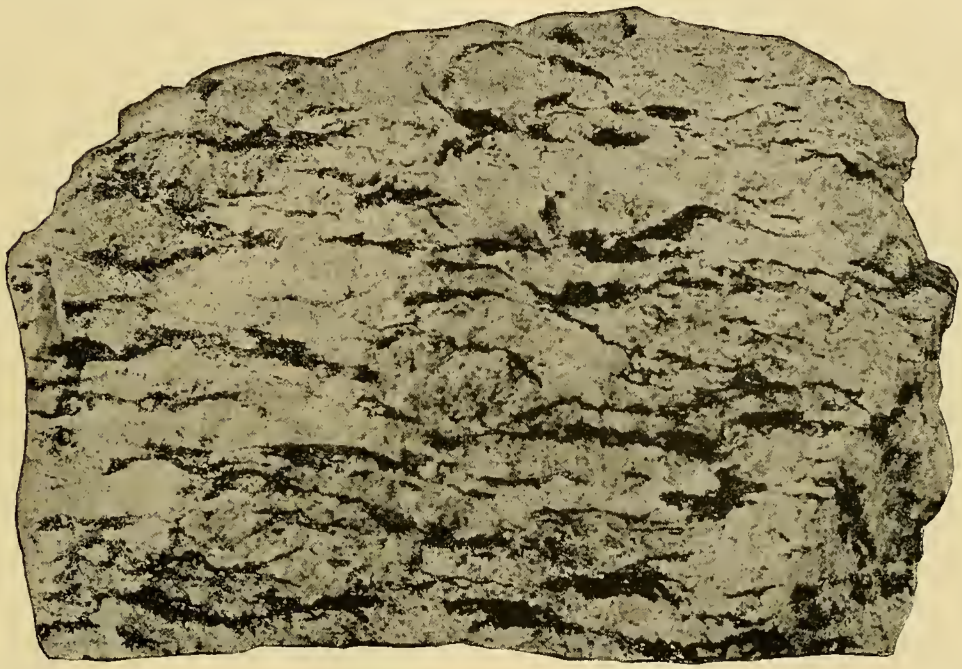

Fig. 12.—Granitoid gneiss (Stamford gneiss), from dump Central shaft. Natural size.
This is the variety with a well-marked gneissoid structure. The dark streaks are composed of the micas inclosing irregularly lenticular areas of feldspar and quartz.

In its most typical form the rock is a coarse banded gneiss (see Fig. 12), composed of long lenticular crystals of pinkish feldspar, flattened lenses of blue quartz, and thin, irregular, greenish layers of a micaceous element (biotite or muscovite, or both) mixed with small epidote crystals, which cause in part the greenish color. We notice at once that the broad cleavages of the feldspar often do not reflect as one surface, but as a number of little disconnected areas, which are often curved—a well-known effect of great pressure in crystalline rocks. The feldspars contain little dull grains of quartz, black specks of mica, and crystals of magnetite, and are often crossed by little branches from the layers of mica outside. At the edges the feldspars often pass very irregularly into the quartz, which then forms the narrow parts of the lens of which the feldspar forms the center ("Augen" structure).

The quartz is characteristically blue, but when crushed by pressure in the rock is often white or sugary in appearance, the blue cores then representing the uncrushed material. In other varieties of this rock it has almost the structure of a coarse granite. The quartz is deep blue, the feldspar colorless and in Carlsbad twins, and the mica layers black. The gneissic structure is almost wanting.

Certain other variations occur in the structure of the gneiss. In the bed of Roaring brook, Stamford, Vermont, the gneiss on the weathered surface has numerous rounded elliptical masses which by the absence of quartz and scarcity of mica stand out by contrast with the rock as a whole, and look like pebbles. They are composed of feldspar aggregates and flakes and patches of biotite. The microscope shows that these feldspars are microcline with some plagioclase and perhaps orthoclase; they have the general structure of the gneiss itself, without the quartz, and are probably of contemporaneous origin. West of Stamford village the rock contains Carlsbad twins of microcline an inch or two across, which weather out from the rock, become rounded by decay, and look like pebbles.

The microscopic characters of this rock are quite uniform; the large feldspars are generally microcline,[1] with whatever crystalline boundary they may have once possessed obliterated by the great mechanical changes they have undergone. The crystals are often faulted and the edges crushed; little veins of secondary quartz, mixed with little grains or crystals of an unstriated feldspar (albite?) traverse them along the fault lines. (See Pl. VII, B.) With a low power the feldspar substance appears cloudy, owing to fluid cavities and little prisms of epidote in great numbers. These epidote grains are sometimes arranged parallel to the twinning planes of the feld-

[1] In the "Geology of Vermont," vol. 2, p. 561, there is an analysis of the feldspar from the Stamford granite, according to which it contains from 64 to 66½ per cent silica, 10 to 11 per cent potash, and 2 to 3½ per cent soda.

spar, sometimes not. In some localities the feldspar contains little round red garnets. Flakes of biotite and muscovite and octahedra of magnetite are common inclusions.

The quartz masses show cataclastic changes in the same way; the original cores of the blue quartz, themselves somewhat strained (seen by using polarized light), are surrounded by masses of broken quartz, the derivation of which from the parent mass can easily be traced. The finer grained portions of the rock are composed of little fragments of microcline broken off from the larger pieces, and small simple crystals, often simple twins, of a feldspar which shows but rarely the multiple twinning of plagioclase, and which resembles the albite of the schists. The layers of mica are composed of muscovite, often with a greenish color like talc, but easily identified by the large axial angle, flakes of dark brown biotite, rarely altered to chlorite, crystals of magnetite, and the omnipresent epidote in prisms or small grains mixed with the micas or inclosed in them. There are occasional imperfect crystals of apatite and prisms of zircon. Some of the magnetite grains are titaniferous, as can be seen by the yellow border of titanite derived from them. In many slides there are quite large crystals of feldspar which have no multiple twinning, extinguish parallel to the cleavage, and are perhaps orthoclase.

Slides of the large porphyritic Carlsbad twins show that they are microcline, filled with irregular bands of a feldspar which extinguishes parallel to $\infty P \breve{\infty}$, and is filled with epidote crystals. Aggregates of biotite plates associated with hornblende crystals are common. There are also masses of ilmenite altered in part to titanite. Sometimes circles of hornblende crystals and biotite plates, which inclose a core of aggregate quartz, by their shape and occurrence suggest a possible replacement of garnets. Grains of quartz and crystals of zircon are common, so that nearly all the constituents of the rock occur within these crystals.

What may have been the origin of this rock it is impossible to say with certainty; it is evident that crushing and the development of mica, quartz, and feldspar, parallel to planes of break and sliding has had a great deal to do with the development of the parallel structure. Viewed from this standpoint it could perfectly well have been an eruptive granite modified by metamorphism. On the other hand, its field relations show its close association with and frequent transition into coarse gneisses which seem to form part of a detrital series.

THE VERMONT FORMATION.

A somewhat varied series of rock overlies this coarse basement gneiss. At one place where there is no possibility of folding (namely, along the pitching axis of Hoosac mountain (see Pl. v, Profiles IX, X). The thickness of this series has been measured between a conformable contact with the granitoid gneiss below and one with the albite-schist above; it is between 600 and 700 feet.

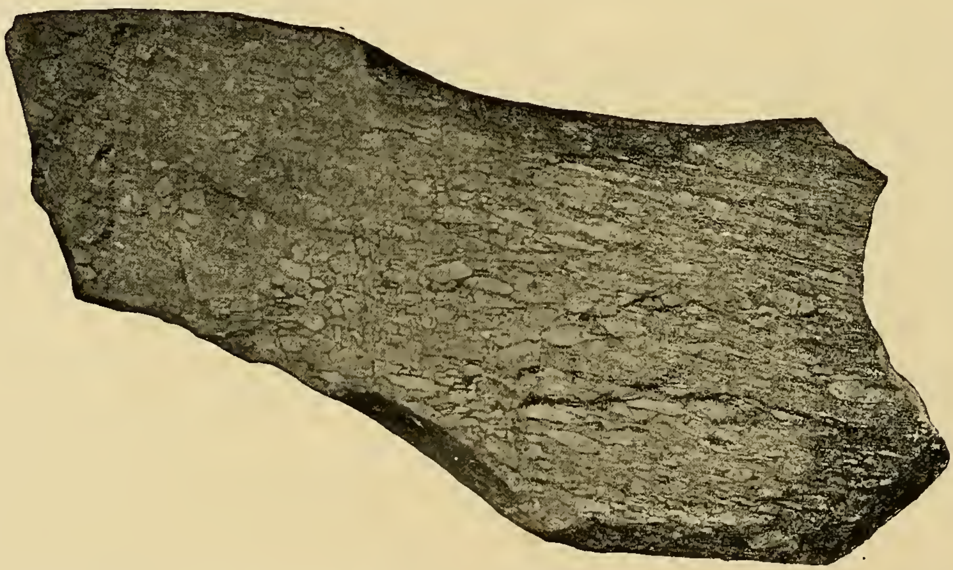

Fig. 13.—Metamorphic conglomerate (Vermont formation). Dump, Central shaft. One-fifth natural size.
This represents two faces of one block at right angles to each other, the line showing the corner. The pebbles are of granulite and blue quartz, some of them 1½ inches in diameter. The different shape of the cross-sections in the two planes is noticeable. By looking closely it will be seen that many pebbles are cut in two by dark lines (biotite), showing that their present shape is due partly to crushing and the formation of new minerals. This is seen on the right side, but not on the left.

This formation contains an infinite series of gradations between coarse gneisses similar to the basement gneisses, finer grained banded gneisses, gneisses composed of quartz and feldspar with but a small amount of the micaceous element, metamorphic gneiss-conglomerates, ordinary quartzite-conglomerates, and quartzites. This series of rocks (represented by gneisses and metamorphic conglomerate) occupies a position in the tunnel section on either side of the central core of granitoid (Stamford) gneiss; while a second narrow belt occurs near the West Portal, adjoining the Hoosic valley (Stockbridge) limestone. On the surface it occupies a large area, especially in the southern part of the field. The quartzites occur generally in or near the Hoosic valley adjacent to the limestone, associated with conglomerates and passing along the strike into the granulitic and gneissic rocks by increase in the amount of feldspar and mica.

FIG. 14.—Metamorphic conglomerate (Vermont formation). Dump, Central shaft. Two-ninths natural size. The larger pebbles are mostly granulite, with some of blue quartz and feldspar. This shows very plainly the shape of the pebbles, which are but little elongated in the plane normal to the picture.

Beginning with the simplest rocks, the quartzites, there are vitreous varieties and crumbly feldspathic varieties passing into gneiss. The vitreous variety occurs in large masses with very obscure stratification, and roughly jointed. It varies in color from snow white to yellow, contains often layers of mica and cubes of pyrite. The microscope shows an even grained, closely interlocking aggregate of little rounded or irregular quartz grains mixed with considerable feldspar in similar irregular grains. Broken or rounded crystals of apatite and zircon and perfect crystals of tourmaline and rutile are common. The feldspar grains are in part microcline, plagioclase, and an untwinned feldspar (orthoclase?). Unless it be the apatite and zircon, no unmodified original clastic elements can be recognized in this rock. According to the usual view of the origin of quartzite, the quartz grains have been enlarged by the growth of new silica, so that the original form is wanting, and the feldspar, judging from its similarity to that of other rocks in which it is undoubtedly metamorphic, has probably a similar origin.

In many localities the quartzites have a crumbly character, so that

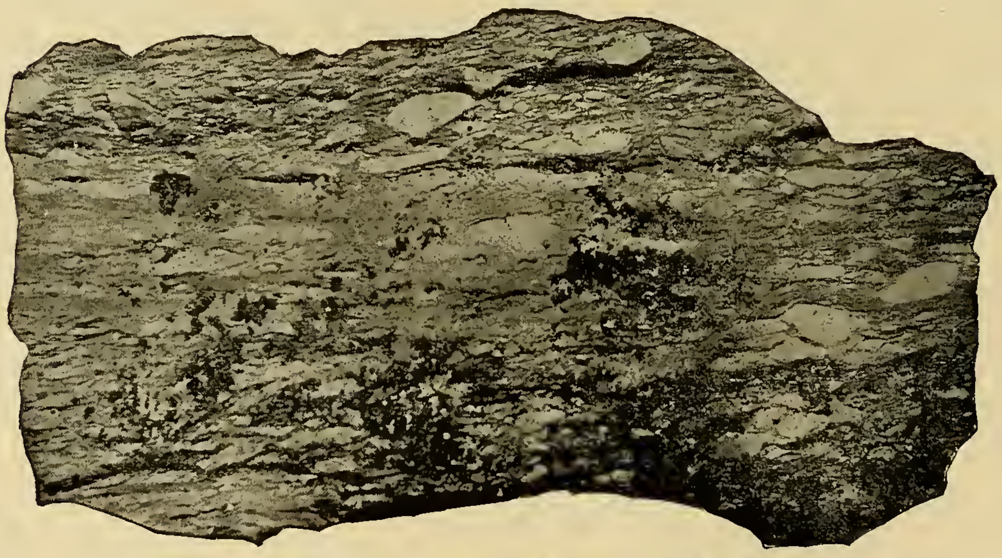

FIG. 15.—Metamorphic conglomerate (Vermont formation), near contact with granitoid gneiss. Top of Hoosac mountain. Fallen block. One-twentieth natural size.

This also shows the production of flattened "pebbles" by crushing and the development of biotite, etc., along crushing and slipping planes. In the right band of the picture this is especially clear. The pebbles here are granulite, passing into a fine grained granite.

they can be picked or shoveled out, and are extensively quarried for glass sand. Prof. J. D. Dana has called attention to this[1] and suggested weathering as a cause, and connected it with the alteration and leaching out of the feldspar. In some of the quarries the percolating water carries down fine kaolin, and forms beds of pipe clay in the bottom of the quarry. But some

[1] On the decay of quartzite, and the formation of sand, kaolin, and crystallized quartz. Am. Jour. Sci., 3d ser., vol. 28, 1884, p. 448.

of these crumbly quartzites show but little feldspar and that quite fresh, while the quartz grains show in the slide abundant signs of great pressure, or even crushing. Some of these quarries are located at sharp folds of the quartzite, so that the crumbly nature of the quartzite may be in part due to a mechanical loosening of the cohesion.

The pure conglomerate-quartzites occur often in the quartzite; for instance, the quartzite resting on the granitoid gneiss (Stamford gneiss) of Clarksburg mountain, in which Mr. Walcott has found fragments of trilobites.[1] contains pebbles of blue quartz, which are often only distinguishable

FIG. 16.—Metamorphic conglomerate (Vermont formation). Dump, Central shaft. One-sixth natural size.
The pebbles are mostly granulitic, but there are some of blue, and some of white quartz. In this type we have round and flat pebbles occurring together, the round ones differing but little in shape in the normal plane. This represents the typical variety of conglomerate.

by their color from the surrounding quartzite cement. The microscope shows that many of these pebbles are composed of an aggregate of little quartz grains derived from a homogeneous mass by crushing, and hence they easily blend with the quartz cement of the rock. They occur often in flattened elongated forms which it is difficult to distinguish from secretions. (See Pl. x, B.)

Some of the quartzites contain abundant calcite grains arranged in stringers, and scattering flakes of muscovite.

Those quartzites in which feldspar becomes more prominent preserve

[1] Am. Jour. Sci., 3d ser., vol. 35, 1888, p. 236.

still the appearance of the purely quartzose varieties. The feldspar occurs in irregular grains fitting in between the quartz. It is partly not twinned (orthoclase?), part plagioclase, generally microline. Little crystals of rutile, prisms of zircon and apatite, flakes of biotite and muscovite, masses of iron hydrate, pyrite, etc., occur in nearly all the specimens. The quartz and feldspars often show evidence of mechanical crushing, and part of the quartz has been thus derived from larger grains. The constituents have a nearly even grain. Although garnet is very rare, it is convenient to call this rock the granulitic type of the quartzite.

From this rock the transition is easy to the white gneiss proper. Several varieties of this may be recognized; a banded one is common, the color varies from gray, yellow to white; sometimes the banding is very fine or the rock is speckled with biotite or muscovite, or both; sometimes the feldspar forms layers separated by layers of mica, or occurs in rounded or irregular masses. The proportions of the elements vary in every conceivable way.

A characteristic feature in the slide is seen in the round grains of feldspar of somewhat larger size than the average of the rock, inclosed in a groundmass composed of little grains of quartz and feldspar in a most intimate admixture, while plates of mica give the rock its banded structure. The larger sized feldspars are typically of a peculiar rounded shape, occurring either in single crystals or in broad simple twins. They are commonly entirely without the polysynthetic twinning of plagioclase in polarized light and might be taken for orthoclase, but their isolation from the powdered rock by the Thoulet solution shows by the specific gravity that they must be generally a soda-lime feldspar near the albite end of the series, although in some rocks they must contain considerable lime, judging by their specific gravity. These feldspars are commonly filled with inclusions of minerals found in the rock outside them—little prisms of epidote, flakes of biotite and muscovite, and little rounded grains of quartz, sometimes arranged like a necklace. These inclusions often lie in planes parallel to the arrangement of the minerals outside the feldspar, and entirely independent of crystallographic directions in the feldspar. (See Pl. VII, A, and Pl. VIII, A.) It is very rare to find any sign of mechanical deformation in these feldspars.

Quartz occurs sometimes in large rounded masses, greatly strained and shattered, and surrounded by a mosaic of small quartz grains. Large pieces of microcline occur, faulted and broken, the cracks filled with an aggregate of little quartz grains and feldspars in simple twins. (See Pl. VII, B.). The groundmass of the rock is a closely interlocking aggregate of quartz grains,

FIG. 17.—Metamorphic conglomerate (Vermont formation). Dump, Central shaft. One-fifth natural size.
The figure represents the banded variety of the rock, in which we find it difficult to draw the line between true pebbles and forms produced by crushing. A glance at the figure, especially at the right side, shows that the extremely pointed ends of some of the apparent pebbles must be produced by the encroachment of the mica layers. Yet these white masses have a lithological character different from that of the "cement," forming, for instance, the broad band near the right side. The former are a fine grained granite or granulite, sometimes blue quartz; the latter a coarser grained mixture of quartz, mica, and some feldspar.

little feldspar grains simply twinned (if at all) and often little grains of microcline of the same form and size. Epidote is often present in large quantities, forming microscopic yellow bands in the rock, and inclosed in the feldspars and micas in little prisms and grains, but not in the quartz.

Titanite, rutile, and tourmaline occur sparsely, as well as little broken prisms of apatite and zircon prisms. The micas occur in homogeneous plates; the interwoven sericitic structure is not common. Magnetite occurs occasionally.

Another variety of these gneisses is distinguished by the evenness of its character and its occurrence along the base of Hoosac mountain as the most western band of the gneisses, in close connection with the quartzites and limestones. The rocks thrown out from the "well" shaft, a few hundred feet west of the west shaft of the tunnel, are typical of this variety. In the hand specimen the rock is a fine grained, evenly banded gray gneiss; the minerals are arranged in layers and the rock is filled with little squarish feldspars. In the slide these feldspars are seen in gently rounded, equidimensional crystals, in simple twins, according to the albite law. The groundmass is composed of little round or ellipsoidal quartz grains and more angular pieces of feldspar (which are in part in simple grains, in part doubly twinned microcline) mixed with threads of muscovite and biotite, the whole so arranged as to produce a schistose structure in the rock. (See Pl. VII, A, and Pl. VIII, A.) Sometimes a band of mica and quartz cuts across a feldspar, the two halves polarizing together and being therefore part of one crystal. The bands of the groundmass bend around the porphyritic feldspars in gentle curves. These feldspars are honeycombed with little drops of quartz and flakes of biotite and muscovite which are often arranged parallel to the structure outside. Octahedra of magnetite are visible in the rock; microscopic crystals of apatite, rutile, and zircon are abundant. In some cases little grains of calcite occur abundantly, even included in the feldspars, and in some localities we find a calciferous gneiss with this same structure, in which the groundmass contains a large amount of calcite in little grains apparently homologous with quartz and feldspar. This variety occurs at several places in the Hoosic valley near the junction between the limestone and quartzite, and represents the Hoosac mountain gneisses nearest to the limestone.

At the base of the white gneiss series the rock in many places passes so gradually into the underlying granitoid gneiss that it is impossible to draw a line between the two. These varieties of the white gneiss are very coarse and feldspathic, but the feldspars are white instead of red as in the granitoid gneiss, and the mica is black. In the slides the structure is essentially the same as that of the granitoid gneiss: the large crystals are microcline, broken, faulted, filled with fluid inclusions, epidote grains, quartz, mica, etc.; while the groundmass is composed of the usual simply twinned feldspars and quartz, mixed with epidote, muscovite, biotite, and other minerals.

At the upper contact of the white gneiss series there are frequent transitions into the overlying albite-schists (Hoosac schist); the transition is caused by the appearance of bands of mica in the white gneiss alternating with bands of feldspar. The latter are often lenticular and composed of the simply twinned feldspars which in the schist are proved to be albite.

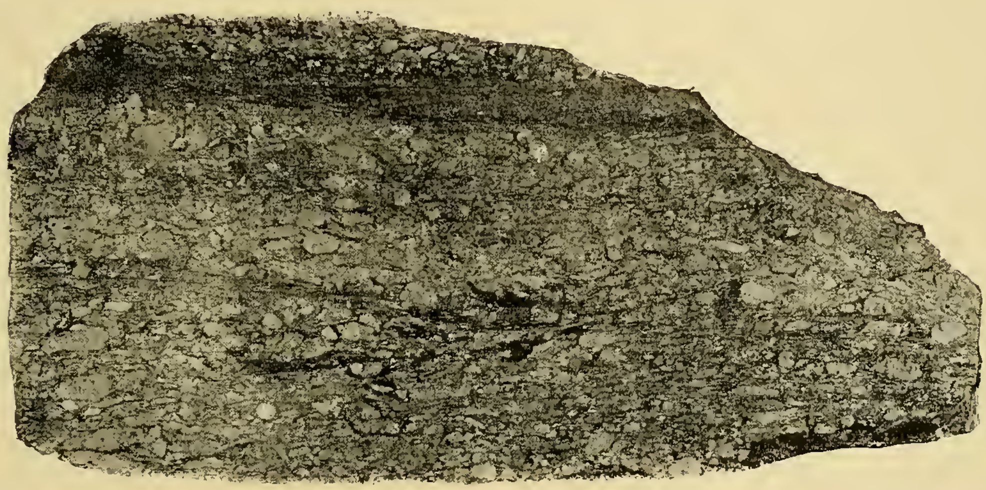

Fig. 18.—Metamorphic conglomorate (Vermont formation). From dump of Central shaft. About one-fourth natural size. This is also the typical conglomerate. The pebbles are mostly of the fine grained granulite type. The fine grained layers, of which a good example is seen near the top, are composed of quartz grains, biotite, and some feldspar. They represent, of course, sand layers in the original sediment which have undergone considerable metamorphism.

The last and perhaps the most important member of the white gneiss series is the metamorphic conglomerate. This rock occupies a large area in the tunnel, occurring on both sides of the central core of granitoid gneiss. Nearly all the varieties of the rock are well shown by the dumps of the central and west shafts of the tunnel. On the surface it is found on the crest of the mountain in the line of the axis of the fold, where the rocks have a gentle northerly dip, and measured between conformable contacts with granitoid gneiss below and schist above, it has a thickness of about 650 feet.

The rock contains pebbles of two varieties: one kind composed of bright blue opalescent quartz, the other resembling a fine grained granite, composed of quartz and feldspar in small grains, speckled with biotite. These pebbles on the average are as large as a walnut, though some are much larger, and they diminish in size until undistinguishable from the elements of the groundmass. The shape is sometimes round, sometimes ellipsoidal, angular, or flattened. In Fig. 13, which gives two sides of a large block, the different cross-section of the pebbles in two planes is shown. The groundmass or cement outside is composed of smaller grains of blue quartz, small feldspars resembling the albite of the schist, and biotite and muscovite in large amount. The effects of crushing in the rock are evident; the pebbles are often traversed by parallel breaks or oblique cracks by which bands of biotite penetrate them, isolating parts of the pebble. Sometimes a pebble is cut in two across its axis by such a band of mica. Thus pebbles, in appearance separate, may have been parts of one individual originally. This crushing action, combined with the formation of the biotite bands, gives many of these original pebbles flattened shapes, so that they appear as layers of granitic material cut off by the biotite bands in planes oblique to their trend. Some varieties of this conglomerate gneiss have a banded structure, due in large part to this crushing action carried to an extreme. (See Fig. 17.) In some cases the pebbles are single crystals of feldspar, and this is occasionally microcline.

Figs. 13–20 show the character of this rock. Some of the pebbles consist of fine grained granite containing small grains of blue quartz. Fine grained gneissoid layers corresponding to the cement often alternate with pebbly layers (see Fig. 18). In some varieties these granite pebbles lie in a very micaceous matrix, composed of small feldspars resembling those of the schist; in others the pebbles become so small that we get an even banded gneiss containing larger grains of blue quartz, the whole forming the ordinary white gneiss previously described. It is then very difficult or impossible to separate the old quartz and feldspar from that formed in situ. The opalescent blue quartz pebbles always retain their round form and are rarely entered by the biotite outside. This shows perhaps a connection between the formation of the biotite and the feldspar substance. The previous description is based on the conglomerate of the tunnel dumps.

On the surface here and there conglomerates are found, often associated with quartzites; in the latter case the pebbles are all quartz and the cement is composed of biotite, muscovite, small feldspar, and magnetite crystals.

On the crest of Hoosac mountain, in Profile IX, Pl. V, the conglomerate is represented principally by the finer grained varieties, but toward the base the pebbles are much larger and are in part not pebbles, but fragments of layers broken up by crushing (see Figs. 15 and 27), giving angular forms.

When we pass westward from the crest of Hoosac mountain, where the conglomerate lies in its normal position, we trace the rock into the white gneiss series on the slopes of the mountain. The pebbles have lost

Fig. 19.—Metamorphic conglomerate (Vermont formation). Dump, Central shaft. About one-seventh natural size. In this variety the pebbles are of much larger size (over 5 inches long), they have the most perfect beach-pebble shape, and are composed of a very fine grained granite, which contrasts sharply with the much coarser gneissoid cement composed of quartz and feldspar grains and mica flakes. The long, white, irregular masses in the center are secondary vein quartz

their distinctness, and without the favorable exposures on the summit and from the tunnel we would not suspect their nature; they appear as white, flat, lenticular masses of quartz and feldspar, which only in rare places suggest a conglomerate (see Pl. X, B), but when one has traced this rock foot by foot into the conglomerate he recognizes the pebbly look at once. It is apparent that this change is connected with stretching of the rock, for the conglomerate is folded over and then turned under on the west flank of the mountain.

The microscope shows that the quartz pebbles are homogeneous masses of quartz, which by optical investigation are seen to have been greatly strained; they have a border of broken quartz which grades into the groundmass. (See Pl. x, A.) They are identical with the blue quartz pebbles of the fossiliferous Cambrian conglomerate (Vermont formation) farther west (Clarksburg mountain, Stone hill). The granite pebbles are composed of crystalloids of microcline, plates of biotite, and grains of quartz. The microcline and quartz are crushed and faulted. Veins of a later quartz traverse the fissures in the feldspars. Crystals of zircon and apatite and plates of chlo-

FIG. 20.—Conglomerate (Vermont formation). Crest of Hoosac mountain south of Spruce hill.
This shows a large cliff of the conglomerate as it occurs in place. The pebbles here are largely blue and white quartz and the cement gneissoid. This is in the upper half of the conglomerate horizon.

rite occur in the feldspar. There are skeleton crystals of magnetite associated with the apatite. The cement is quite similar to that of the white gneiss.

Without here going into the much disputed question of metamorphic conglomerates in general, which are found in so many terranes of stratified crystalline rocks,[1] it may be said that the reasons for considering this particular rock a true conglomerate and not a gneiss containing peculiar con-

[1] Cf. A. Winchell, Am. Geologist, vol. 3, pp. 143 and 256. Also C. H. Hitchcock, Am. Geologist, vol. 3, p. 253.

cretionary forms, are, first, the shape and distribution of these forms (well shown in the figures) and the alternations parallel to the stratification (determined by contact with other rocks) of bands of coarse and fine material; second, the diverse nature of the pebbles in the same rock (blue quartz, white quartz, granulitic rock, granite, etc.); and, third, the frequent transitions in the field into quartzite and quartzite-conglomerate. The production of at least part of the mica, feldspar, and quartz of the cement in situ has been indicated, and also the effects produced by crushing.

THE HOOSAC SCHIST.

The next member of the series is the albite-schist (see Figs. 21, 22, 23, and Pl. VIII, B), which conformably overlies the conglomerate on top of

FIG. 21.—Albite schist (Hoosac schist). Dump, Central shaft. One-twelfth natural size. This is the type with thin flat quartz layers (the white streaks) and gentle crumpling.

Hoosac mountain, extending northward for miles into Vermont. On the east it extends southward along the east side of the conglomerate and on the west in a narrow band along the west slopes of the mountain, curving around so as to almost join that on the east. In Hoosic valley masses of these schists occur adjoining the Stockbridge limestone and then lying between it and the Hoosac gneisses of the Vermont formation. In the tunnel a band occurs several thousand feet wide (see Pl. V, Profile III) between the west band of white gneisses and those of the eastern core, and again at about the center of the tunnel, under the central shaft, they come in east of the conglomerate and fill the eastern half of the tunnel to about 6,000 feet from the east portal, where they are succeeded by the silvery-green schists (Rowe schists) to the east portal.

Among the perfectly fresh material found at the tunnel dumps a shiny black glistening rock is typical, containing parallel layers of white quartz which thin out and disappear in the rock. These flat lenses are sometimes very irregular and crumpled by large folds or small puckerings. It is found that they correspond to the plane of stratification of the rock wherever the schist is seen in contact with other rocks. The black, shiny part of the rock is filled with sparkling glassy crystals of feldspar, either in imperfect rounded crystals or in simple twins, which contain inclusions of mica, garnet, etc. The basal cleavage planes are sometimes bounded by the brachypinacoid (M), the prisms T and l, and the macrodome, etc., but the crystals are in general rounded or even angular.

The feldspar twins are according to the albite law, and the crystal is divided into two symmetrical halves, or else the composition-plane is irregular, one half taking up most of the crystal, leaving a small strip to the other. The rock was powdered and the feldspar, separated by the Thoulet solution, analyzed by Mr. R. B. Riggs in the laboratory of the U. S. Geological Survey at Washington with the following result:

SiO_2	69·69
Al_2O_3	18·60
CaO	trace
MgO	0·20
Na_2O	10·28
K_2O	0·40
Ignition	0·42
	99·59

CO_2 (Combustion), 0·77 = 0·44C.

Basal cleavage pieces with the simple twin give an extinction 4° oblique to the twinning-plane and second cleavage (M). Twins measured in the goniometer give angles of 172° 46′ to 172° 50′ between the basal cleavages of the two twins. The chemical and physical properties are therefore those of albite. These albite crystals vary from large to small;

they lie in planes roughly parallel to the schistosity of the rock, but their crystallographic directions have no such relation.

Some varieties of the rock at the shaft are filled with red garnets in dodecahedral crystals.

The surface rock has the same characters, but with certain variations due in part to weathering. The shiny black variety is found here and there, but the rock is commonly greenish, indicating a certain amount of chlorite; it varies from light to dark green. Garnets are sometimes contained in the rock, especially at the base, where a garnetiferous horizon occurs. Feldspar

Fig. 22.—Albite schist (Hoosac schist). Dump, Central shaft. One-sixth natural size.
Here the quartz lenses are more irregular and thicker; the little white specks dotting the rock are the crystals of albite.

is often present with the garnet. These schists are identical in every detail with the schists of Mount Greylock.

The porphyritic albites are prominent in the slide. Simple twins are common, but polysynthetic twins rare. Single crystals are common. They have a rounded lenticular or flat shape. The groundmass outside the feldspar is composed of muscovite and biotite, or muscovite alone, chlorite, grains and aggregate lenses of quartz, magnetite in octahedra or grains, apatite, tourmaline, and rutile. Ottrelite is found in some localities The micas of the groundmass bend around the albites in gentle curves (see Pl. VIII, B), and often a band of mica cuts across a feldspar. The albite contains inclusions of muscovite, biotite, chlorite, quartz, magnetite, rutile, etc., according to their presence or absence in the rock. It is common to see them in curving bands parallel to the banding of the same minerals outside the feldspar. These feldspars evidently crystallized contemporaneously with the other minerals in the rock.

FIG. 23.—Albite-schist (Hoosac schist). Dump, Central shaft. About one-eighth natural size. Here the quartz lenses are again prominent. It is found that they are always parallel to the stratification.

The quartz occurs in little grains often arranged in stringers. The muscovite is either in stout plates or is a mass of interlacing fibers or plates—the structure characteristic of sericite. Biotite and chlorite occur in plates or irregular scales; the two minerals occur sometimes side by side in the same piece without any sharp boundary between the two, so that the chlorite has the appearance of an alteration product of the biotite.[1] When the chlorite occurs independently in stout plates it has a marked pleochroism varying from green to yellow green, an extinction several degrees oblique to the cleavage and twinning with OP as composition-plane. Tourmaline and apatite occur in imperfect prisms, magnetite in octahedra, and rutile in small crystals, often with the heart-shaped twins.

In several specimens a little ottrelite has been noticed, and at one locality this mineral occurs in such amount that the rock must be called an ottrelite-schist. This is interesting in that it still further proves the lithological identity of the Hoosac, Greylock, and Berkshire schists, since this mineral is found in all three of these formations. The hand specimen is a shiny, greenish schist containing crystals of garnet and dotted with little black ottrelite crystals. In the slide the ottrelite occurs in comparatively large crystals with the characteristic indigo-blue, yellow, olive-green pleochroism. The extinction is several degrees oblique to the cleavage; it is twinned parallel to the base, and basal sections give a faint bisectrix. It occurs associated with irregular masses of black ore; a number of small prisms of ottrelite surround a plate of the ore (ilmenite?). Plates of muscovite and a few grains of quartz compose the rest of the rock. The ottrelite is filled with little prisms of rutile with the "knee"-twin. Basal sections show the blue color, with vibrations parallel to b (at right angles to the axial plane), and the yellow green parallel to a; hence it has the pleochroism of most ottrelites.[2]

In this schist we recognize no clastic element with certainty and the feldspar, quartz, micas, etc., appear to have formed contemporaneously, for the feldspars contain inclusions of the other elements and in turn are sometimes crossed by tongues of mica and quartz.

While the term "schist" is applied to this rock owing to its frequent coarsely crystalline character, yet its great similarity should be noted to crystalline rocks described from Germany and elsewhere as *albite-phyllites*, which contain porphyritic albites with similar inclusions, micas, magnetite, etc.

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[1] This association of biotite and chlorite is common in the hydromica schists of the Green mountains and is often suggestive of hydration by weathering.

[2] Cf. Rosenbusch: Physiographie, vol. 1, p. 494.

THE STOCKBRIDGE LIMESTONE.

The next rock is the limestone found in Hoosic valley at the base of Hoosac mountain and covering the valley west to the base of the Greylock mountain mass. It occurs in contact with the Vermont quartzite and with both the Berkshire and Hoosac schists at several places in the valley.

The rock is generally a coarsely crystalline white marble banded with layers of yellow muscovite or dark graphitic substances, and containing layers of bluish quartz. Layers of quartzite are frequent in the limestone and the change from one to the other is gradual. Microscopically the limestone consists of grains of calcite, a few of quartz, flakes of mica, etc.

It has been mentioned that one variety of the fine grained white gneiss often contains considerable calcite, thus forming in some sense a transition between the Stockbridge limestone and the Vermont gneiss. A much more perfect transition is found between the limestone and Hoosac schist. The best case of this kind is found in the "Cove," in Cheshire, where the ground is filled with large angular blocks of this rock, which occurs in place in one ledge. These rocks resemble a micaceous white limestone filled with little dark grains or imperfect crystals of feldspar. In the slide the rock is composed of a mass of calcite grains, with here and there single grains of quartz, or an aggregate of several grains, plates of muscovite and often of chlorite and biotite, and large porphyritic feldspar grains in single crystals or simple twins, very rarely showing polysynthetic twinning. These feldspars contain inclusions of mica, quartz, iron ore, rutile, and calcite, and are in every way identical with the albites of the albite-schists, although the exact species of plagioclase has not been determined. The calcite seems to play the part which the quartz does in the schists: it sends tongues into the feldspars, or cuts them in two, and gives one the impression by its inclusions in the feldspar and its occurrence with the quartz and mica that it is of contemporaneous origin with the feldspar, mica, and quartz. Rutile needles, and masses of ore (ilmenite?) occur in curved bands in these feldspars. Small irregular masses of microcline occur sometimes among the quartz grains of the rock.

On the Greylock side of the valley about 300 yards west of Maple Grove station there occur outcrops of a similar feldspathic limestone. Part of the feldspar is here in broad simple twins, but part is microcline in similar crystals. The feldspar of this rock needs further investigation.

The fine-grained silvery green or green schists (Rowe schists) which occupy a strip on the extreme eastern border of the map, overlying the albite-schist (Hoosac), have not been microscopically investigated by the writer.

AMPHIBOLITES.

Last to be described are heavy dark rocks, generally fine grained, in which the eye recognizes dark crystalloids of hornblende and irregular

Fig. 24.—Amphibolite. Mount Holly, Vermont.
A band of amphibolite 2 feet wide, interstratified with gneiss and crumpled with it in a large double fold. The structure of the amphibolite coincides in every detail with that of the gneiss.

patches of feldspar and cubes of pyrite. In the finer grained varieties the rock has a glistening surface due to plates of biotite in films mixed with the hornblende, and the rock then has a somewhat schistose structure. They rocks have been found in several localities, in all but one case in beds parallel to the structure of the inclosing gneisses and contorted with them.

These rocks occur abundantly in the Green mountains. The most remarkable occurrence is perhaps near Mount Holly and Wallingford, Vt., 70 miles north of Hoosac mountain. Here, too, the Cambro-Silurian limestone and Cambrian quartzite (Vermont formation) are succeeded by gneissic rocks in the east, which form the central divide of the Green mountains. In the region east of Rutland and directly south of the high mountain mass of the Killington peaks there is a marked break in the general topography in an east to west zone, 10 to 15 miles wide from north to south, which is characterized by the flat character of the hills. The north to south ridge character of the Green mountains is interrupted here, and replaced by gently

Fig. 25.—Amphibolite. Same locality as 24.
The amphibolite is interstratified here with quartzite.

rounded elliptical hills forming an open grazing country. The railroad from Bellows Falls to Rutland crosses the axis of the mountains at this place. We notice that the soil is colored a deep red and soon find that this is due to the decay of masses of these amphibolites, which are interbanded with the highly contorted gneisses of the region. Figs. 24, 25, 26 show this very well. These bands of rock are parallel to the strata of the gneiss in most cases, but here and there send out across the strata tongues which have a fine grain at contact and show that these rocks are intrusions. They have in general a perfectly parallel structure, which curves with that of the inclos ing gneisses, but also a marked columnar jointing. The form of the hills and the very existence of this topographical belt seem due to the rapid erosion of these rocks. Their field relations show that they are of intrusive origin—dikes, in fact, injected parallel to the strata and then crumpled and metamorphosed—and their microscopical characters agree with those of similar rocks, described by Lossen, Teale, and many others, which have been recognized as altered dikes. They correspond in part to the "metamorphic diorites" of Hawes.[1] They are briefly described by President Hitchcock in the Geology of Vermont, Vol. II, p. 578, where the remark is make that they "may be only huge dikes."

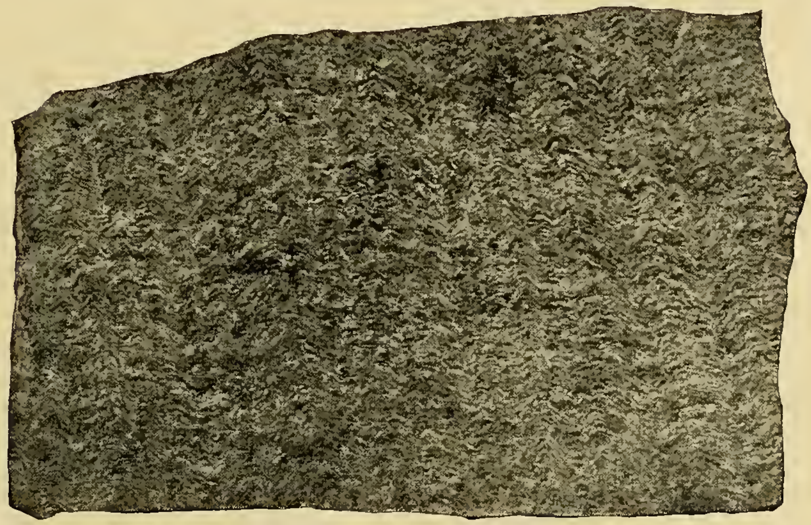


FIG. 26.—Crumpled amphibolite, Mount Holly, Vermont. Natural size.

The white bands are feldspar, the dark bands hornblende principally. The vertical groovings which coincide with the line of apices of the folds (the specimen standing as in nature) show but faintly in the figure, and are doubtless caused by rain flowing over the vertical surface and following the depressions between the small folds.

In the hand specimen we see a dark heavy rock, with very faint parallel structure in the coarse varieties. Studied in thin section these rocks have very uniform characters; the least altered forms, of coarser grain, are composed of crystalloids of hornblende and rounded grains of plagioclase feldspar. The hornblende is a massive brownish-green variety in short irregular crystalloids, the central parts of which are filled with a dark opaque substance, which, with high powers, is resolved into a mass of little crystals of rutile; they sometimes inclose crystals of apatite. In some

[1] Lithology of New Hampshire, p. 225.

parts of the rock these grains of hornblende fit in between rounded grains of a twinned plagioclase. In other places in the rock the hornblende is seen to have a narrow fringe of light green pleochroic hornblende (see Pl. IX, B), massive and not fibrous; in other grains this entirely replaces the brown hornblende, or only little cores of the latter are left. At the same time the feldspars in those parts of the rock are filled with small acicular crystals of the same green hornblende associated with small grains of plagioclase, and minute veins composed of these two minerals often cross the original feldspars by narrow fissures (see Pl. IX, A). The extreme change consists in the entire replacement in parts of the rock of the feldspar and hornblende by an aggregate of these small secondary feldspars, with a little quartz and epidote in abundance. It is plain that the original plagioclase and brown hornblende has changed to a new plagioclase, green hornblende, some quartz, epidote (taking part of the lime from the feldspar), and a little calcite.

In another form the rock is a fine-grained amphibolite composed of crystalloids of bright green or bluish green hornblende, rarely inclosing small cores of original brown hornblende, and plates of biotite; both these minerals lie in planes, causing the schistose structure. The remaining space is filled with little plagioclases which are rarely polysynthetically twinned and are filled with grains and prisms of epidote. Grains of titanite surround small black cores of original titaniferous iron ore and sometimes the titanite grains run out in stringers parallel to the schistosity. These feldspars contain, in addition to epidote, titanite grains, needles of hornblende, biotite flakes, and grains of quartz. In some rocks the little prisms have the characters of zoisite instead of epidote. These feldspars may occur in broad simple twins like the albite of the schists, or may be polysynthetically twinned. The feldspar was isolated from several rocks by the Thoulet solution and found to be always plagioclase, generally toward the albite end of the series. The hornblende contains titanite and epidote; the plates of biotite contain rutile needles.

A few of these rocks carry irregular masses of red garnet which alter to chlorite; they inclose masses of magnetite and green hornblende with cores of brown hornblende. The garnet seems to be contemporaneous with the feldspar.

One vertical dike of this rock at Stamford, Vermont, contains blue quartz grains and broken crystals of microcline, which have been taken from the country rock of the dike, the granitoid gneiss (Stamford granite).

GEOLOGY.

For convenience of description the region covered by the map (Pl. I) may be divided as follows:

First. The Hoosac tunnel.

Second. The region embracing the central part of Hoosac mountain from the tunnel line on the north to the point in Cheshire where the crest of the mountain makes an offset to the west.

Third. The area covered by the schists occupying the northern and eartern parts of the map.

Fourth. The region south of Cheshire and of the Hoosic valley.

Fifth. Hoosic valley schist.

Sixth. The region around Clarksburg mountain and Stamford, Vermont.

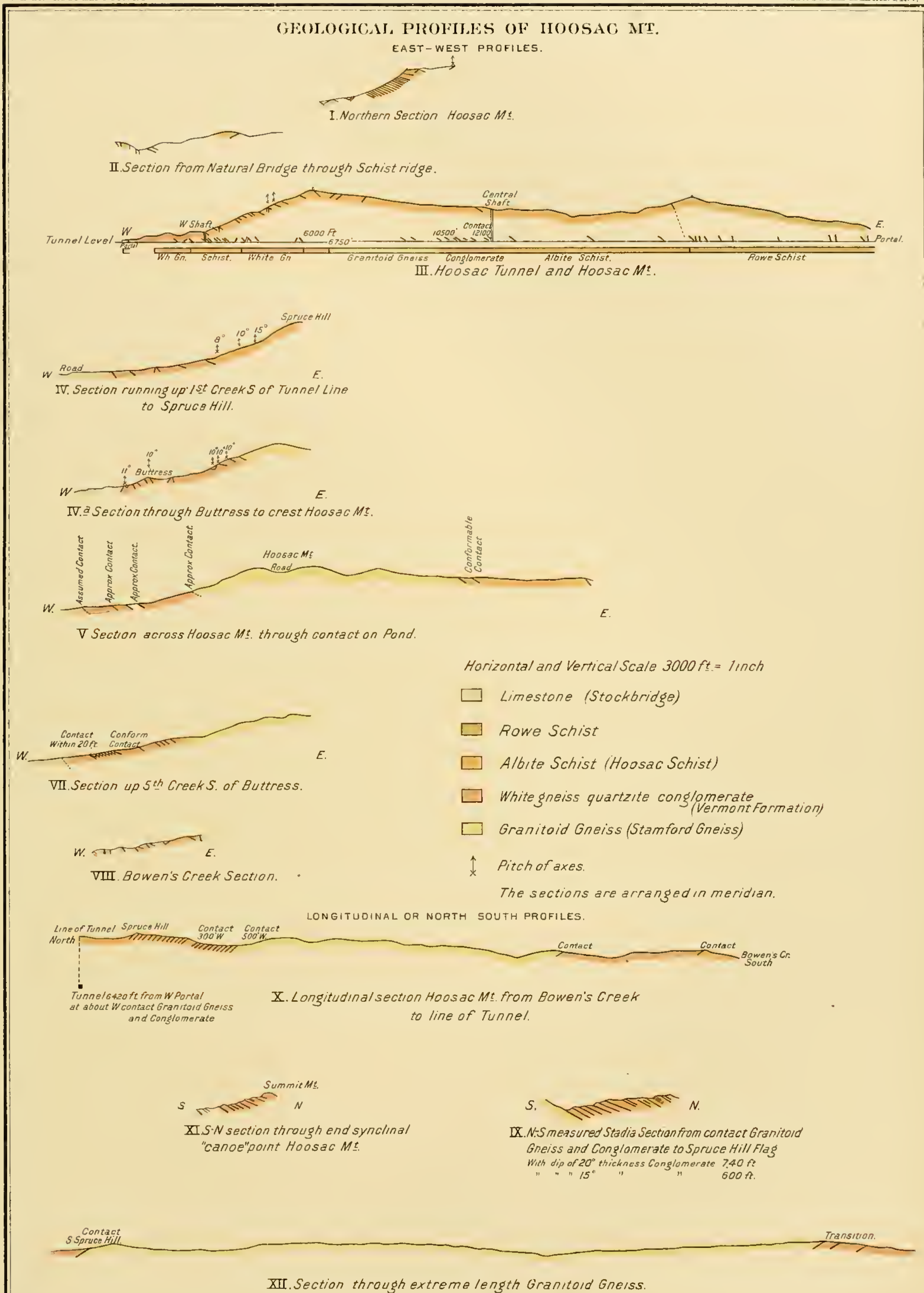
THE HOOSAC TUNNEL.

This great engineering work is $4\frac{3}{4}$ miles long, entering the base of Hoosac mountain from the Hoosic valley on the west, and running in a nearly due east direction across the trend of the range. Two shafts have been sunk; the deepest, the central shaft, near the center of the tunnel, is about 1,000 feet deep, descending from the basin-like depression on top of the mountain. (See Pl. V, Profile III). The other, the west shaft, is not quite half a mile from the west portal, and is 325 feet deep. About 1,000 feet west of the west shaft, a small shaft called the "well" was sunk, on the dump of which specimens of the rock are found.

The tunnel itself is a large double-track opening, which, starting from the Stockbridge limestone at the west portal, passes through all the rocks of the series at least once. But several things combine to greatly lessen its value as a geological section of the core of the mountain. A considerable proportion of the tunnel is now bricked over, and only in the manholes, every 250 feet, can the rock be seen; and secondly, the covering of soot and smoke on the rock is very thick, making it necessary to get fresh surfaces by hammering. The difficulties of working by lamplight in the smoke of passing trains are also considerable. Moreover, that part of the tunnel which would have afforded the most important contact for determining the relations of the Stockbridge limestone to the Hoosac mountain rocks is entirely bricked over; it lies in the decomposed rock which caused so much trouble during the building of the tunnel. Therefore, while the general distribution of the rocks is easily found in the tunnel, much less was done in the way of determining relations by contact than would have been possible under more favorable conditions.

In the following description the reader is referred to Profile III, Pl. V.

Starting at the west end of the tunnel we find the Stockbridge limestone of Hoosic valley in the long open cut which leads to the tunnel mouth, and passing under the masonry of the portal; the dip alternates in a series of small folds, sometimes east, sometimes west. From the portal for 2,700 feet the tunnel is bricked, but at several of the manholes we find rock in place. At a little over 1,600 feet we find in a manhole the first occurrence of the fine-grained variety of gneiss with small porphyritic feldspars, and the same rock again at about 1,900 feet in. Near 2,000 feet the albite-schist (Hoosac schist) is found in all of the manholes to about 3,800 feet. Then by transitional rocks this passes into the white gneisses which extend to 6,000 feet, where by gradual transition they pass into the coarse granitoid gneiss; this rock runs as far as 10,500 feet, then after 250 feet of bricking the conglomerate-gneiss is found at 10,770 feet, and this extends to 12,100 feet, where the albite-schist series is found in conformable contact with the conglomerate-gneiss. The albite-schist, succeeded by the Rowe schist, is then found through the rest of the tunnel. We find then in the tunnel, going in from the west: first the limestone, which extends into the tunnel proper a short distance, but is now entirely bricked in; then the fine grained, banded, white gneiss (Vermont formation), extending to about 2,000 feet from the portal; then the albite-schist for 1,750 feet; next the white gneiss (conglomerate-gneiss) series (Vermont) for a little over 2,000 feet; then the granitoid gneiss (Stamford gneiss) for a little over 4,000 feet; then white gneiss-conglomerate for 1,500 feet; and the schist formation (Hoosac schist overlaid by Rowe schist) for the rest of the way, or about 12,900 feet, of which the last 6,000 is occupied by the greenish sericitic or chloritic Rowe schist.



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As regards the structural observations it was not practicable to attempt these in detail; in the first or westerly band of white gneiss, found only in manholes, both east and west dips were observed, and no contact was seen with the next rock—the albite schist.

This next band, the albite-schist, has in general an easterly dip, but towards the contact with the next band of white gneiss has a very steep dip varying from east to west. There is a conformable contact and transition between the two rocks.

In the next band of white gneiss dips were noted varying from steep east to west: the observations are put down in the section. At about 6,000 feet the rock becomes coarser in character, corresponding to the white gneisses, transitional to the granitoid; it contains frequent round pebbles of blue quartz, corresponding to the conglomerate found in the dumps of the tunnel. From here for about 700 feet we have transitions to the coarse gneiss; lenses or layers of fine-grained gneiss are frequently seen. Nearly a whole day was spent here in searching for a contact, by careful hammering, but none could be found; there is an evident transition, as observed elsewhere at points outside the tunnel.

The area of the coarse granitoid gneiss contains rock of an even character; whatever structure exists by arrangement of mica planes, etc., remains flat or gently rolling east and west. The east contact between this rock and the conglomerate-gneiss is concealed by the brickwork.

This east band of the conglomerate-gneiss, as on the surface, is characterized by a steady, well-marked easterly dip of 20° to 30°, and this ends very near the central shaft, where the rock is overlain by the albite-schist; its thickness is accordingly about 600 feet, which agrees closely with that found on the surface. The structural planes of the two rocks are absolutely conformable, both dipping east about 25°. The line of contact is easily found; within a few inches of rock they pass into each other without a break. From here through the rest of the tunnel only the albite-schist, passing in the last 6,000 feet into fine-grained greenish schists, is found. The dip of the structural planes is always steep east. The rock varies in character as on the surface, in color, coarseness, amount of albite, quartz lenses, etc.

The main facts then brought out in the tunnel are that there is a large central mass of coarse granitoid gneiss (Stamford gneiss) forming the core of Hoosac mountain; that this is flanked on either side by a band of the white gneiss-conglomerate (Vermont formation), the eastern band having a steady east dip and conformably overlain by the albite-schist series, the western band being broader, with varying dips passing by gradual transitions into the coarse gneiss, and bounded on the west by a narrow band of the albite-schist (Hoosac schist); the contact between the two rocks being conformable and transitional. The schist band is succeeded on the west by another band of fine-grained white gneiss (Vermont) and this in turn by limestone (Stockbridge), no contacts being observed. We shall speak of this anticlinal structure further, after describing the geology of the surface of the mountain.

THE REGION EMBRACING THE CENTRAL PART OF HOOSAC MOUNTAIN.

The map shows the distribution of the formations in this area. The central part, forming the crest of the mountain, is occupied by a long irregularly oval area of the granitoid gneiss, the long axis of which runs nearly north and south parallel to the trend of the mountain, with a length of 5 miles and a width at one place of $1\frac{1}{4}$ miles. This is surrounded by a zone of the white gneiss series (Vermont) about one-half mile wide, which at the southern end of the granitoid gneiss core expands into a broad area of white gneiss-quartzite, extending down to the southern border of the map. To the east, the great expanse of the albite-schists (Hoosac schist) borders the zone of the white gneiss-conglomerate, running in an almost straight line along the whole eastern edge of that formation to the southern edge of the sheet. It circles around this formation to the north, forming the surface rock in the whole northern part of the Hoosac mountain, and sends a long narrow tongue down on the west side of the white gneiss zone, which bends around with this at the southern end of the granitoid gneiss area, and becomes gradually thinner until it can be only doubtfully traced by loose blocks at the extreme point of the curve.

Lying west of this tongue of Hoosac schist we have another area of fine grained white gneisses or quartzites, with a variable width, which disappear under the drift a little north of the tunnel, and at the south join the great mass of white gneiss at the southern end.

Finally the limestone borders this last area on the west. The relations of these rocks—granitoid gneiss, white gneiss, and metamorphic conglomerate—are best shown at the extreme northern end of the area of the first rock (see Profile IX, Pl. V) on the crest of Hoosac mountain. The granitoid gneiss is here of the typical variety, with bright blue quartz and a structure well marked in the mass. This dips about 10° to 15° a little east of north. In a little north and south cleft, just south of a small swamp, we find this rock in contact with the overlying conglomerate gneiss. Fig. 27 shows this. The series dips 20° in a direction north 25° east. The lower part

FIG. 27.—Contact of granitoid gneiss (Stamford gneiss) and metamorphic conglomerate (Vermont formation). Top of Hoosac mountain. South of Spruce hill.

The contact runs from the left hand lower corner to the right hand upper corner. This conglomerate is also shown in Fig. 15. Notice that the lines of structure of the gneiss follow conformably those of the conglomerate.

of the exposure is formed of typical granitoid gneiss. Upon this the lower beds of the white gneiss-conglomerate rest conformably. In the latter rock it is apparent at once that crushing has largely affected the form of the pebbles. To this cause their flattened character and truncation by oblique planes of mica is undoubtedly due, and yet they are in large part pebbles. Not only their general shape, but the lithological distinctness shows this. They are composed either of massive white quartz, or blue quartz, or smoky quartz, or in some cases of a white granulite, or lastly of a fine grained white gneiss containing blue quartz and biotite. In one large pebble the gneissoid structure in it is quite oblique. It is easy to see that this conformity of contact in these two rocks, both of which have so much secondary structure developed in connection with crushing, may be due to the crushing itself. From this contact northward the crest of Hoosac mountain makes a sharp rise in a series of bluffs facing south, the top of each bluff sloping gently to the north. Profiles A and B, Pl. XI, show this feature well. In Pl. XI, B, we are looking west; in the hollow at the extreme left is the contact spoken of, and the white gneiss-conglomerate extends to a point shown about the middle of the picture, and is then succeeded by the albite-schist. The gentle northerly dip of the whole series can easily be seen by the slope of all the steps of the crest to the north (right). See also Pl. V, Profile IX. Starting from the granitoid gneiss at the base we find a thickness of 600 to 700 feet of this white gneiss conglomerate with a very steady northerly dip of 15° to 20°. At the base the rock is quite coarse, as previously described. As we ascend in the series it becomes gradually finer grained. The granulite-gneiss pebbles become smaller and smaller and are more frequently crossed by the mica of the groundmass; the quartz pebbles, and especially those of blue quartz, preserve their rounded character. Fig. 20 (from a large cliff of this medium grained rock) shows this character finely; the large pebbles are mainly of blue quartz. As we go higher up the rock becomes more and more even grained until we get a finely banded muscovite-biotite-gneiss. In many places the conglomerate is finely crumpled or fluted, the axis of these foldings gently inclined, parallel to dip. Pl. X, B, shows this character; here the flattened lenticular masses we call pebbles are themselves gently folded with the rest of the rock. At the top of the conglomerate this rock is overlain conformably by the Hoosac albite-schis. series. At a distance of half a foot from the latter, thin bands of extremely garnetiferous Hoosac schist alternate with bands of the fine grained conglomerates, forming a well marked transition. The rock at the base of the Hoosac schist group is extremely garnetiferous and of a dark, almost black, dense character, with little feldspar. This garnetiferous character at contact with the white gneiss is almost constant in this region and seems to extend some distance above the contact, perhaps 50 or 100 feet; in the space covered by our Profile IX, Pl. V, (which is plotted from a stadia section, checked by triangulation) it will be seen that there is nearly 800 feet of the albite-schist to the summit of Spruce hill, where the section stops. The schist preserves its gentle northerly dip throughout, with a quite uniform character, often very rich in the albite crystals.

The profile we have just described gives us the key and starting point for the geology of Hoosac mountain. As will be seen later, this profile is taken at the northern end of the overturned anticlinal axis of Hoosac mountain, the whole axis having this gentle pitch or plunge to the north which causes the dip of 15° to 20° northerly. The granitoid gneiss disappears at the surface here and is found again in the center of the Hoosac tunnel in the same meridian line, but 1,400 feet lower in level. Although the northerly pitch of the axis has here brought the top of the arch of the granitoid gneiss far below the surface, enough of the arch remains above the tunnel to allow a length of several thousand feet of the excavation to lie in this rock. (See Profile X, Pl. V.)

Now going back to the contact of granitoid gneiss and gneiss-conglomerate at the south end of Profile IX, Pl. V, and tracing the contact of the two rocks westward, in a few hundred feet we come to the extreme west crest of Hoosac mountain overlooking the valley (see Pl. IV). Here we find the continuation of the two rocks in contact again with the same strike and dip. The granitoid gneiss runs a hundred yards north and then disappears; the white gneiss-conglomerate makes a sharp turn over the prong of the other rock and comes in on the west side of it, on the slope of the mountain; the white gneiss strikes north 40° east and dips 50° west, instead of striking north 67° west and dipping northeast. The manner in which one rock mantles over the other can be seen very plainly; at the turn they are within 20 feet of each other. The successive outcrops of the white gneiss on lines radiating out from this point of the turn show the same curving around of the outcrops from a northwest to a northeast strike.

Following in the same way the top of the conglomerate towards the west, we find it strikes northwest until the extreme west crest of the mountain is reached, closely overlain by the Hoosac schist; the outcrops then suddenly turn and descend the slope of the mountain obliquely in a northwest direction, followed closely by the overlying schist. The rocks here are very much crumpled; the axes of the crumplings have a steady direction about north 10° east and a gentle northerly inclination of 10° to 15°, while the actual line of outcrop runs northwest down the mountain. In this way the schist mantles over the conglomerate and follows it down; gradually the line of outcrops turns and runs nearly straight down the mountain until the extreme point is reached nearly half way down to the valley. Here we find the gneiss striking north 10° east and pitching 10° to 15° northerly, very much crumpled, and passing under a cliff of the schist likewise crumpled. The two rocks are here again connected by transitional layers in which bands of white gneiss alternate with bands of schist, and the gneiss contains a great abundance of the porphyritic feldspars; the schist is also the dark garnetiferous variety. At this point the same change of position previously described occurs, namely by a sudden turn, which can be traced by connected outcrops; the schist comes in on the west side of the white gneiss with a strike north 10° east, a strong northerly pitch, and a dip of the foliation (very much crumpled) generally steep west. The reader is referred to the map (Pl. IV) for the graphic presentation of these facts; the outcrops have been carefully traced step by step and important points located by placing flags in the trees and putting in the points by the plane table. Note how closely the apices of the turn in the granitoid gneiss and white gneiss coincide, showing the conformity of the series. After the rocks have made this turn so that the overlying formations come to lie successively west of one another, there is no difficulty in tracing their course to the south along the side of the mountain. From the turn in the contact between granitoid gneiss and white gneiss-conglomerate, the line of contact runs obliquely down the mountain in a south by west direction for about 2 miles, where it reaches its lowest point topographically; the actual contact has not been found, although the two rocks commonly come close together, but talus from the granitoid gneiss conceals the contact. The white gneiss often forms a flat bench 100 or 200 feet wide. The structure of the white gneiss, as mentioned before, dips very steeply west just after the turn; within a quarter of a mile it is found to dip near the contact with the granitoid gently east, from 10° to 25°; but commonly the rock is greatly crumpled, the axis of the crumples running north 20° east and having a strong northerly pitch. Profile IV[a], Pl. V, shows this feature.

In the same way the contact between the white gneiss and the band of Hoosac albite-schist can be traced south from the point where we left it. Both rocks are very much crumpled, the axis of the crumples striking a little east of north and strongly inclined to the north; the contact can be found within a few feet; the structure of the two rocks in the large cliffs can be seen on the average to be nearly perpendicular or dipping steep west. The schist near the contact is the dark garnetiferous variety found at the base of that rock on the top of the mountain.

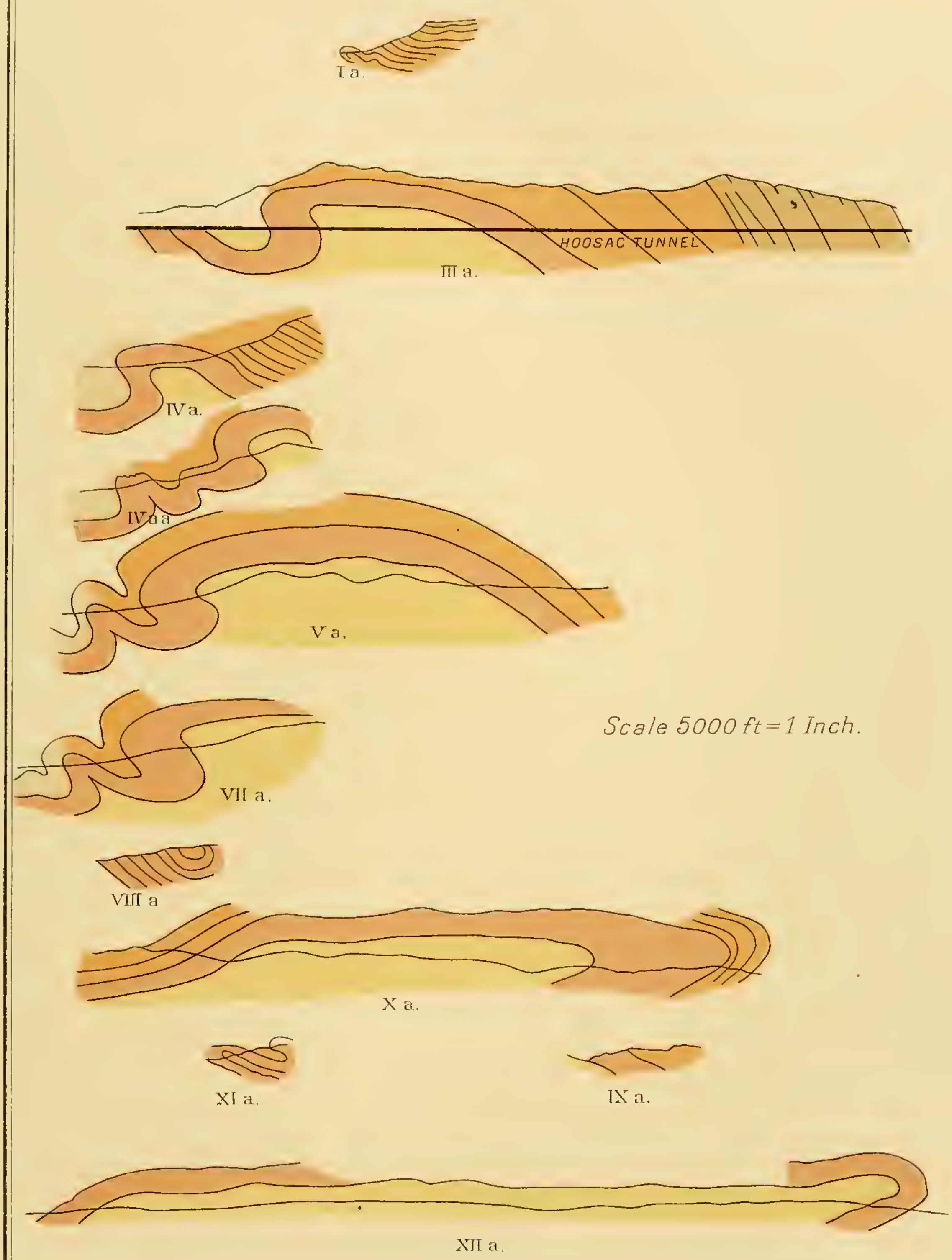
As will be seen from the map the schist forms only a narrow band, bordered again on the west by another area of gneiss.

We will now take up the relations of the granitoid gneiss and white gneiss-conglomerate and trace them around from the point where they were last seen at the turn. As said above the line runs obliquely down the mountain side, the structure of the two rocks dipping gently east; that is to say, the white gneiss dips in under the granitoid instead of overlying it. Near what is marked Southwick creek on the map the granitoid gneiss reaches its most westerly extension and its lowest topographical level, and from here the outcrops begin to rise and to turn gradually and run southeast. Pl. V, Profile VII, which runs up Southwick creek, shows this relation well; the white gneiss has a steady flat moderate easterly dip carrying it under the granitoid gneiss. At about this point we notice a transition from the white gneiss to the granitoid; the white gneisses are coarse and very feldspathic, so that it is almost impossible to find any definite line of demarkation between the two rocks. Continuing a third of a mile south from Southwick creek we come to the place where Profile X, Pl. V, crosses the contact of the two rocks. The actual junction of the two rocks is found here in so far as there can be said to be a junction. The strike is north 40° west and the dip 15° east. Within a hundred feet horizontal the rock forms a transition between the coarse typical granitoid gneiss on one side and the fine-grained banded white gneisses on the other. From here the contact turns and ascends the mountain rapidly, the coarse transitional gneiss making it always impossible to find any exact contact; the strike is north 25° west and the dip flat east. After reaching the crest of the mountain the line of contact turns approximately north and south with north and south strike of the structure of both rocks, the dip of the structural plane is rolling and often is westerly. When we come to the extreme end of the west side of the granitoid gneiss area, where the line makes a sharp turn to the east, we find well marked in both rocks and in the transitional forms a strike nearly due east and west and a rather gentle northerly dip (strike north 77° to 85° west dip 10° northerly). The coarse transitional rocks belonging to the white gneiss series can be traced to the round spur about 1 mile north of Savoy Hollow, where by a sudden crumpling the rocks turn around to a north to south strike and an easterly dip and then run northward.

If we go back to the contact of the two rocks first described (south of Spruce hill), and follow it *east*, we find that the line of contact preserves its east and west strike for half a mile and then begins to turn southerly. The conglomerate preserves its character fairly well for that distance; but half a mile further the strike is about north and south or north 10° west, showing considerable variations, but there is always an easterly dip of 20°. The line of contact here turns southerly and is concealed by drift. Half a mile farther south we find the coarse transitional gneiss, instead of the conglomerate, striking here north 42° west and dipping 45° east. For three-quarters of a mile this rock continues until we come to the shore of the second pond crossing Profile v, Pl. v. Around the shores of this pond the relations of the rocks are well exposed. On the west shore the typical granitoid gneiss occurs with blue quartz, with a north to south strike and easterly dip of the structure. For 1,000 feet east of here we have a series of outcrops, partly in the water, which consist of the coarse transitional gneiss, often containing granulitic lenses that resemble the pebbles of the conglomerate. There are many loose outcrops of the genuine conglomerate with blue quartz, granulite, and gneiss pebbles, which make it very probable that ledges of this rock exist here. Half way across the pond we find the contact of these coarse transitional gneisses with the Hoosac albite-schist, the latter resting on the gneiss and the structure of the two rocks absolutely conformable—strike north 10° east, dip 25° easterly. The schist is very garnetiferous, as usual near the contact, and covers the rest of the sheet from the contact east to the Rowe schist. The area covered by these transitional coarse gneisses therefore occupies the geological position of the conglomerate-gneiss, a fact which the occurrence of the "loose ledges" of conglomerate seems to confirm. North of the lake the continuation of this coarse transitional gneiss is found at intervals with the same strike and dip. From here for $2\frac{1}{2}$ miles south the place which should be occupied by the white gneiss-conglomerate is covered with drift, and not a single outcrop is found. The albite-schist, with a constant north to south strike, borders on the east and the granitoid gneiss on the west. Opposite the post-office of Savoy Center the next outcrop is found. This is quite conglomeratic in aspect, with round, blue quartz or granulite pebbles, and a strike north 15° west and dip 45° east. Intervening between this and the typical granitoid gneiss to the west we find the same coarse transitional gneiss, with somewhat varying strike and dip. Continuing south from this last exposure, on the road leading to Savoy hollow, we find occasional outcrops of coarse transitional gneiss with the same nearly north to south strike and easterly dip. This brings us about to the extreme point of the area of granitoid gneiss and to the white gneiss-conglomerate band followed around from the west side. The relations of the rocks at this point are peculiar and deserve a special description. The topography here is well marked. It is easily seen on the map that a long spur runs out from the point of the granitoid gneiss for a mile and more toward Savoy hollow. This spur is caused by the meeting of the white gneisses of the east and west areas, those on the east coming down with a north to south strike and easterly dip, those on the west striking across with a nearly east to west strike and northerly dip. We find on the spur the rocks very sharply crumpled, representing the sudden turn of strike and dip; some layers striking east and west can be traced to the place where they curve around and run southerly with a steep easterly dip. At one point on the spur, about a mile north of Savoy hollow, we find a curious curving series of outcrops of a very coarse porphyritic gneiss, containing large rounded feldspar crystals, blue quartz, etc.—an "Augen" gneiss. The outcrops on the east side strike north 5° west and dip about vertically. This gradually curves around to an east and west strike and steep southerly dip, then to a northwest strike and northerly dip—that is, the layers circle around in the space of a few hundred feet, giving a canoe-shaped fold. The development of the very large porphyritic feldspars just in the turn is also significant. In short, this space, so marked topographically, is the place where part of the layers of the white gneiss are crumpled and pinched together in the extreme point of the great fold which we have been describing. It will be seen from what has been said that the central part and crest of Hoosac mountain is composed of a great anticlinal fold in the three members of the series—granitoid gneiss (Stamford gneiss), metamorphic conglomerate (Vermont formation), and albite-schist (Hoosac schist)—and that this fold has a pitch or inclination of its axis of 10° to 15° to the northward, while the western side has been pushed in under or overturned, this overturn continuing into the southwestern part. The beds are in inverted order on the west and southwest sides; in normal order on the north and east sides. By reason of the pitch of the axis the same rock occurs in the tunnel, 1 mile north of the last appearance of the granitoid gneiss on the surface, flanked on both sides by the conglomerate and albite-schist; these two formations on the east side dipping east, overlying the granitoid gneiss in normal order On the west we find the same transitions between granitoid gneiss and white gneiss-conglomerate that were observed on the surface, and a nearly vertical structure. Profiles x and xii, Pl. v, give these relations graphically.

The belt of Hoosac schist which is seen on the map to run around the central gneiss and nearly to join the great mass of schist on the east, starts off from the main mass as a broad tongue, narrowing rapidly to a small constant width. At various points its top and bottom contacts with the gneiss on either side have been observed. Over the tunnel this schist can not be found in definite contact with the western gneiss; on the contrary, there is a gradual transition, which can be seen in the outcrops on the slope of the mountain above the west shaft. We hardly find here in the schist what we can call a dip of any kind—simply the usual fluting, with the strong northerly pitch of the axes. Following the band down to a point some hundred yards north of Profile iv^{a}, Pl. v, we find here the east contact of the schist and white gneiss. The schist is very garnetiferous, as

GEOLOGICAL PROFILES OF HOOSAC MOUNTAIN GENERALIZED.



elsewhere. Both rocks have their structure vertical with the small folds, pitching 10° to 15° northerly. In Profile IV[a], Pl. V, itself we get another contact. From here for 2¼ miles to Profile V, Pl. V, the black schist is concealed; then outcrops occur with easterly dip; east and west contacts with the gneiss are concealed. In the creek of Profile VII, Pl. V, we have a long series of outcrops of the schist with the easterly contact beautifully shown, the westerly within a few feet. These schists are extremely crumpled, as shown by the quartz lenses; these crumples pitch gently northerly. The rock is very garnetiferous near the eastern contact with the white gneiss; in other places feldspathic. At the east contact we have the white gneiss dipping 20° easterly; it is a white, muscovitic variety. The schist layers can be seen within less than 4 feet of strata from the base of the gneiss, dipping gently under it; intervening ledges are covered by the water or soil. It indicates perfect conformity, both series dipping east. After forming a series of cascades over this schist the creek runs out on a level and we find here the rock succeeded by outcrops of micaceous quartzite or fine grained gneiss, with same strike (north 10° east) and dip 25° east; the distance covered from one rock to the other is 25 feet horizontally.

For half a mile south from the upper contact of Profile VII, Pl. V, it can be traced very closely with the same strike and gentle easterly dip, the contact being found often within a few feet and the structure of the two rocks being conformable. At a mile from this contact we come to Profile X, Pl. V. Here the actual contact was again easily found in the rocky cliff, both white gneiss and black garnetiferous schist much crumpled, but with a general easterly dip of 10° to 15°. The strike is north 25° to 30° west and the small crumples pitch northerly 10° to 15°. This inclination affects the topography; Fig. 10, p. 43, represents this spur, in which the gentle slope towards the left of the picture (north) is due to the pitch of the rocks. The lower contact is not found here. In Profile VIII, Pl. V, we have this schist again outcropping, but neither contact.

A mile farther, on the north fork of Tophet creek, in a deep gorge, we find fine exposures of the schist, much crumpled, and at the head of the gorge its contact with the overlying white gneiss, which here again contains transitional layers of micaceous gneiss. Both strike north 10° west and dip 15° easterly. From this contact the line of the two rocks is easily followed over the hills to the south fork of Tophet creek, 1 mile. Here, after crossing numerous exposures of the western band of gneiss, the creek falls over cliffs of the typical albite-schist with same strike (north 10° west), and gentle easterly dip under the overlying white gneiss, with which it is connected by transitional beds as before. The schist is always garnetiferous.

From here for half a mile the schist can only be traced by loose pieces and one outcrop until we reach the corner of the mountain; here we find it again in place and the contact with the overlying gneiss is within 2 feet of strata. Both are conformable in structure and strike north 45° west dipping 25° northerly. Here both rocks are turning to assume their east to west strike at the extreme point of the turn (curve), and only crumpled outcrops of schist are found, as is usual in these turns.

Following the schist east one-half mile we find it overlying the western band of white gneiss, which has here curved around so as to lie south; the upper contact is not seen; the schist is garnetiferous and passes into the underlying white gneiss by micaceous layers. The strike is north 75° east, dip 25° northerly, and one-quarter mile farther east cliffs of the garnetiferous schist are found striking east and west and dipping 20° north, closely and conformably underlain by the southern band of white gneiss. From here for a mile only fragments of the schist are found. Within a quarter of a mile of the extreme turn a small outcrop of feldspathic schist, exposing a thickness of 30 feet, is interstratified with the fine-grained gneiss; strike north 40° west, dip 20° north. One-half a mile farther in the line of the strike of the gneisses, which are curving at the extreme point from an east to west to a north to south strike, a solitary outcrop of garnetiferous and feldspathic schist is found, with a vertical dip and strike north 10° east, which represents probably the last trace of this tongue, which we have followed continuously from the main mass. It seems to be squeezed out in the folds of white gneiss.

We come now to the band of gneiss (Vermont formation) lying west of this band of Hoosac schist. All of this gneiss follows closely the schist around to the extreme southeast point, where it merges into the great area of gneiss in the southern part of the map. The gneiss of this area has a uniform and peculiar character; it belongs to the fine grained porphyritic gneiss already described and has a tendency to pass into micaceous quartzite or even pure quartzite.

The first exposure found is on the side of the mountain about 1 mile north of the tunnel line, where it is within a few feet of the albite-schist, which here extends up the mountain. Both rocks are conformable, strike north 30° east, dip 60° east; to the north the rock is covered with glacial drift, so that it is uncertain where it finally disappears, but the two bands of albite-schist come close together both east and west of it. This rock shows a remarkable tendency to disintegrate. This "rotten gneiss" caused great expense and loss of time in building the western part of the tunnel. At the tunnel line outcrops of this rock are found on the surface at the west shaft and on the mountain above for over 100 feet, when they are succeeded by the schist; but transitional rocks made it impossible to draw a line. Toward the west edge of this gneiss band, a few hundred yards north of the tunnel line, an old iron mine alongside the road is composed of a massive quartzite containing masses of limonitic iron ore, the structure of which is not determinable. This gneiss was also found in the tunnel at several manholes, and in the creek just south of the tunnel line we find several outcrops of this rock as indicated on the map, all striking about north 20° east and dipping east at varying angles. Also a few hundred yards south of the portal of the tunnel we have an outcrop the strike of which would carry it very close to the portal.

When we come to the sharp little hill of Profile IV^a ("the Buttress") we have fine exposures of this gneiss (see Plate V). It is plain, from this section, that in this band of gneiss we have considerable folding. One sharp anticlinal is plainly shown here with many smaller crumples. There are several hundred feet of covered space between the western outcrop of gneiss and easternmost of limestone, but the contact with the schist is very close. The folds of this gneiss have a strong northerly pitch of as much as 10° in Profile IV^a.

From Profile IV^a for 1¾ miles to Profile VII we have only two or three scattering outcrops of this rock (see Pl. V). At Profile VII it is represented by one outcrop of micaceous quartzite closely underlying and conformable to the overlying schist; strike north 10° east, dip 30° easterly. Three-quarters of a mile south, in the next creek, two or three outcrops of micaceous feldspathic quartzite strike north 10° west, dip 25° east. The curve of the strike has begun here.

Broad benches strewn with glacial drift cover this rock in all this part of the mountain. At this place, opposite the north part of the town of Adams, the line of junction of the limestone with the gneiss band seems to make a curve westward, for we find one outcrop of this gneiss in a small quarry near Adams. The strike is north 10° west, dip 25° east. A few hundred yards south, in the creek marked Anthonys creek, we get outcrops of a similar gneiss; strike north 8° west, dip 50° easterly. Below this a few feet we find a series of outcrops of a massive micaceous quartzite, the bedding of which dips 25° to 30° easterly and strikes north 15° west. A little lower down along the road we find the Stockbridge limestone striking north 15° west, dip 25° east; we find this within a few feet of the quartzite along the road. Then in the bank there is a crumbly transitional rock between the limestone and quartzite, so that the Stockbridge limestone and this quartzite seems to form the same rock, and the fine grained banded gneiss appears to overlie the quartzite.

In the canyon of Tophet creek we have cliffs of the limestone with varying strike and dip. Ascending the creek, near the upper edge of the canyon, we find a large ledge of massive vitreous quartzite which strikes northwest and is overlaid by large loose ledges of the fine grained gneiss, striking north 35° west, dip east 50°. Several hundred feet along the strike south, and in the creek bed there is the conformable contact of a small piece of massive quartzite overlaid east by the gneiss, both dipping east and striking north 10° west. Still farther south on Tophet creek, near the entrance to Bowens creek, there are extensive ledges of the fine grained gneiss striking north and south and dipping east. It is therefore evident that this rock, underlain to the west by a massive quartzite, is succeeded by the limestone, and that the limestone and quartzite pass into each other by transitions. In the canyon of Tophet creek this contact is concealed; it is some hundred feet from the quartzite to the first cliff of limestone.

For 2,000 feet east across the strike from the fine grained gneiss at the entrance of Bowens creek into Tophet creek, a gently sloping bench conceals all outcrops; then in Bowens creek we have Profile VIII giving us a typical section through this band of gneiss, the rock varying between a vitreous quartzite, micaceous quartzite, and the fine grained gneiss typical of this area. Above, the schist and then the eastern gneiss succeed the first mentioned rocks. As will be seen in Profile VIII the rocks have a moderate easterly dip with few variations.

The next exposure is on the north fork of Tophet creek, where this series begins a few feet below the lowest outcrop of the schist, and forms a continuation of the canyon of the creek for over half a mile; the rock makes great cliffs and bluffs with a well marked strike north 10° west and a gentle dip of 10° to 15° east. Rock one hundred and fifty feet thick can be seen; the south fork of Tophet creek shows the same; here the rocks are much more quartzose—often a massive quartzite—and the dips are irregular, in some cases northerly.

Just below the junction of the two forks of Tophet creek the water flows around the north end of an elliptical hill (Burlingames hill), the crest of which is formed by a large outcrop of massive vitreous quartzite which strikes north 10° east, dips 25° east. At the north end of the hill the creek exposes outcrops of rock with the same strike, and an easterly dip of 15°, in which a lenticular mass of massive quartzite passes into a dark feldspathic biotite schist resembling the transitions between albite schist and gneiss. The quartzite passes laterally as well as vertically into the schist, showing the sudden transitions of which these rocks are capable. We have a broad drift-covered area extending 1½ miles from the outcrops of massive quartzite on this hill to the limestone outcrops, and south to the schist in Cheshire; an area which contains no outcrops whatever. From the south fork of Tophet creek we get no outcrops of this band of gneiss until we get to the "point" of the mountain. This locality is a large "canoe;" that is, the strata turn suddenly from a north and south strike and easterly dip to an east and west strike with northerly dip. We have described the schist band and the manner in which it is overlain and underlain by white gneiss. The underlying white gneisses corresponding to this western band occur in great cliffs with a strike north 40° west and dip 15° to 20° north. From their base to the base of the schist they correspond to a thickness of 450 feet but on the theory of duplication to only half that amount, having the fine-grained banded character of this western area of gneisses. These cliffs strike along east with the same strike and dip. The profile of Hoosac mountain seen from a distance shows plainly the step-like series of terraces, sloping gently northward, which correspond to these beds of gneiss. (See Pl. v, Profile xi.) Following this band of white gneiss east, at about one-half mile from the point of the mountain the strike has turned to north 75° east. One-quarter mile farther there are again cliffs of this rock striking nearly east and west and dipping north; the schist overlies here again. Beyond this point it is no longer possible to separate this band of gneiss from that band nearest the granitoid gneiss; they merge together, after the band of schist has thinned out, in the great area of contorted white gneiss in the southern part of the field.

NORTHERN AND EASTERN SCHIST AREA.

It will be seen that the whole northern third of the region, and a broad strip along the east, is occupied by the albite schist, with commonly an easterly dip and north to south strike. It will be noticed that there are changes in the dip to the north; on the line of the axis of the mountain the dip is north, but there is in general great uniformity, as there is in the case of this rock in the tunnel. Of course this steady dip does not mean a true monocline, but rather a series of folds overthrown to the west and eroded. No attempt has been made in the field to unravel the more minute details of this structure; this was done only in important places, where the relations of the other rocks require it. It is also possible that troughs of the overlying Rowe schist occur in this northern area, but the facts have not been definitely ascertained. The quartz lenses and layers, so abundant in the schist, are found to be always parallel to the bedding at contacts with other rocks of the series, where the alternation of material shows which is the plane of stratification, and hence these lenses can be provisionally accepted as indications of stratification elsewhere, when, as is often the case, the rock has a marked transverse cleavage.[1] In the vicinity of Spruce hill the schist

[1] On the Greylock side cleavage lamination and stratification in the schists have been carefully distinguished by Mr. Dale.

continues for some distance to have its northerly pitch, but small folds begin to come in, as for instance in Profile III, Pl. v, parallel to the tunnel line, on the west summit of the mountain, where a small syncline exists. Note in this profile on the west slope of the mountain how the dips roll from east to west with commonly a northerly pitch. It is characteristic of this rock that it forms gorges and waterfalls along the side of the mountain. Hoosac mountain presents an unbroken wall for 12 miles in Massachusetts, extending into Vermont. Profile I, Pl. v, gives one of the best sections through the schist; it extends from the valley to the summit of Hoosac mountain and shows the structure here by an almost continuous section. On the slope of the mountain proper, the rocks have a gentle easterly dip, while at the base there is considerable rolling. On top of the mountain there is again a gentle rolling of the rocks.

The west end of Profile I is separated by a shallow, drift-covered depression a few hundred yards wide from a long north and south ridge in the valley (see map) on the summit and sides of which we find the typical Hoosac albite schist, often very garnetiferous, extending in an almost straight line to near the western portal of the tunnel, where it stops. This ridge of schist is everywhere separated from that of Hoosac mountain by this small, drift-covered hollow, so that we have only the lithological identity to correlate by. This rock is succeeded by the limestone on the west throughout its extent. Profile II, Pl. v, shows the relations of the rocks across this ridge, beginning with those which are exposed on the north fork of the Hoosic river in North Adams. The Stockbridge limestone has here its most northern outcrop in Hoosic valley and strikes north 20° east, the dip varies considerably; the rock is much folded, a fact well shown in a quarry and chasm in the limestone at the "Natural Bridge." This rock is succeeded within 60 feet by a schist with conformable strike, and dip east 40°. About 800 feet across the strike east from this contact, with one or two intervening outcrops of schist, we have a high bluff along the river, composed of micaceous schistose limestone, effervescing strongly with acid, striking north 25° east and dipping 25° east. This bluff extends for some distance and is 70 feet high, exposing a considerable thickness of the rock. At the top of the bluff there is a flat bench, gently rising to the east (evidently formed by this rock) for nearly 500 feet, then rising more steeply to the summit of this ridge, where we find the albite schist with the same strike, but greatly crumpled dip. There are no outcrops between the top of this bluff of limestone and the schist, about 3,000 feet horizontally. No outcrops are found for a mile south of this place along the strike, then we find the limestone in a small quarry, striking north 35° east, dip 35° east. This limestone at the top of the quarry is conformably overlaid by a black schist, and 50 feet distant across the strike an outcrop of the typical Hoosac schist has the same strike, crumpled in small folds with a northerly pitch. It looks very much like a transition from limestone to schist at these places. From here there are few outcrops down to the West Portal, where the schist entirely runs out just north of the tunnel. There seems to be in this ridge a trough of schist with a pretty steady north to south strike and crumpled dip. The outcrops can be traced along the summit of the ridge almost continuously.

The northern area of schist overlying the Vermont conglomerate south of Spruce hill soon turns from the east and west strike as we go east to the steady north and south strike of the eastern border, and runs from here with an almost straight line to the southern border of the sheet. The conformable contact with the white gneiss (Vermont) at the pond (Profile v, Pl. v) has already been mentioned; the line of contact runs about 9 miles to a point about 1 mile northeast of Windsor Hill, where the contact is well shown between the fine grained white gneiss and the schist; strike north 20° east, dip steep east. There are here transitional beds between the gneiss and schist formed by very micaceous layers. Over a mile due east of Windsor Hill the same thing occurs again; the schists are here very garnetiferous. The Rowe schists, which lie east of and hence overlie the Hoosac (albite) schist, have been mentioned previously. They appear on the map (Pl. I) as a narrow strip at the eastern edge, passing into the Hoosac schist at the line of contact. They will be described in their more general relations in a forthcoming memoir of Prof. B. K. Emerson covering the territory east of the map.

THE REGION SOUTH OF CHESHIRE AND OF THE HOOSIC VALLEY.

The area of gneisses (Vermont formation) south and southeast of the granitoid gneiss can best be described by beginning at the southwest end.

In the Hoosic valley here we have the Stockbridge limestone crossing the valley from the Greylock side and running close up to the slope of the hills on the east side. This limestone is succeeded by a broad band of quartzite (Vermont) on the slopes of the hills and this again by a series of gneisses (Vermont) which extend to the crest and back from it, east. In the southwest part of the map the quartzite occurs in a long ridge running northerly and southerly, just east of the Hoosic river. It is a very massive vitreous variety, the dip of which is obscure. A little hollow, perhaps a hundred feet wide, separates it from the gneisses on the east, which strike north 25° east parallel to the trend of the quartzite, and dip first west then east—much folded. Following 1 mile north from here without finding outcrops, we come to a creek running into the large pond in the valley a few hundred yards north of Berkshire depot. Just where this creek issues from the sloping benches a little east of the road we find well-marked ledges of the limestone striking north 37° east, dip steep westerly; 125 feet east the next outcrop dips east 65° and is in contact conformably with a calcareous quartzite; for one-half mile or more up this creek beds of this calcareous quartzite are found, in places massive quartzite; then, after a covered interval of 400 feet, we find ledges of laminated gneiss (quartzose) dipping also east 50° (strike north 40° east); farther up the creek this gneiss is succeeded by coarse gneisses with blue quartz resembling the granitoid, also dipping east. We have here a transition of the Stockbridge limestone into the Vermont quartzite, and this is in turn overlain by gneisses, the whole series inverted. The limestone is covered along the contact from here north to Cheshire. The line of contact between quartzite and gneiss can be easily followed north along the side of the mountain, the two rocks never quite in contact, until we reach a point on the side of the mountain half a mile south of the north end of the pond; here the quartzite and underlying fine grained gneiss make a sharp turn, and, as is so often the case in this region, in the turn the rocks are not eroded away. The southernmost outcrop of a laminated quartzite strikes north 45° east, dips 60° west; across a little ravine to the north this curves to strike east and west, dip 50° northerly. It is overlain by a large bed of very massive vitreous quartzite, and near the outcrops of the latter numerous angular blocks of a quartzite-breccia cemented by limonite occur—a rock often found in these sharp turns in the quartzite and connected with the crushing. The laminated quartzite is closely underlain by curving outcrops of a rather coarse layer gneiss, in which long flat bands of feldspathic material, blue quartz, and biotite alternate. This again is conformably underlain by outcrops of fine-grained biotite gneiss. These outcrops are separated a few feet horizontally. Their contacts must be within a few inches of strata, and they are perfectly conformable. This proves the structural conformity of this massive quartzite series with the underlying gneisses. A mile and a half north of this we find the sharp point of the mountain, on the east side of which the valley makes a bay or "cove" running a mile south. This "point" of the mountain is formed by the massive quartzite, south to the crest, and also at its north and west base, where the quartzite is quarried for sand, and the stream makes a fine cut through it. One-eighth mile east of Cheshire village the quartzite is quarried from a large mass, striking north 30° west, dipping 20° northerly, and can be followed southeast for at least one-quarter of a mile with the same strike and dip. Along the west side of this point of the mountain the quartzite has been quarried in several places. About 1 mile south of Cheshire, near the north end of the pond, at a sand mine, the quartzite strikes north 40° to 50° east, dips 20° west, while northeast of here, on the slopes of the mountain, near another old sand-mine, the strike is north 80° west, dip 20° northerly. This "point" of the mountain therefore represents an anticline in the quartzite, collapsed and overthrown to the east—a prow, or inverted canoe. On the top of the crest of the mountain the quartzite forms the slopes and highest crests, striking north 15° west, dip 15° east; in the east slopes it strikes north 30° west, dips 30° east.

Going back to the quartzite quarry, in a little ravine off the road, an outcrop of calcareous quartzite is found overlain within 10 feet by an impure limestone. The strike is about north 20° west, dip about 30° northeast. A few hundred yards further north outcrops of limestone are found striking north 50° west, dipping 45° east. It is to be noticed therefore that the limestone also circles around the quartzite to the north and strikes south to lie east of the quartzite, forming in part at least the bay or "cove" of the valley. No outcrop, however, of the limestone in place is found in this cove. The southern rim of the cove is formed by massive quartzite which strikes north 85° east, dip 50° northerly, gradually turning on both sides of the cove to a north and south strike. Thus on the east side of the cove it strikes north 65° east and dips west; approaching the succeeding point of the mountain it strikes north and south, then at the extreme of this point north 37° west, dip vertical. The extreme point is formed by a very massive vitreous quartzite, 150 yards north of which there is a loose outcrop of limestone, probably not in place. There are also small ledges of schist on the west edge of the cove which probably are in place; strike north 32° east, dip west steep. They show that the schist area north of the cove runs in here near the quartzite. As we go east from this second point the quartzite strikes north 30° west, dip northeast, then begins to strike east and west and dip northerly with a constant strike. About a mile from this second "point," or sharp canoe, in the quartzite, we come to a very important locality, where this massive quartzite and conglomerate passes along the strike into the white gneiss series of Hoosac mountain. Half a mile from the second "point" the massive quartzite runs up the hill, striking north 80° east, dip northerly 30°. A great thickness of massive quartzite is exposed here; in some cases there are beds of well-marked conglomerate with quartz pebbles; this quartzite runs in great cliffs up the side of the mountain (see map, Pl. I). As it approaches the summit it becomes more and more micaceous. At the summit and near the north to south road running to Windsor, it changes along the strike within 200 feet into a fine-grained white gneiss. The quartzite on this hill is separated into two divisions by a layer of black biotite schist of some thickness The rocks turn around this hill, which represents a quartzite dome (the rocks dipping north), and then by their dip are carried down to Dry brook, to which they can be easily traced by long cliffs and scattering outcrops.

This brings us to the area between Dry brook on the south, the "point of the mountain" north (where the central series of Hoosac mountain makes its sharp turn to the east), and the western border of the Hoosac schists on the east. The rocks we find in this area are varieties of the white gneiss, often coarse. Along the western border there are quartzites and conglomerates interbanded with gneisses, while the large area of schist in Hoosic valley extends east into the gneiss area. Three general peculiarities of structure may be noted (see map, Pl. I):

First. In the west part of the area, between Dry brook and the curve north (about 2 miles from north to south and 1 mile wide), there is a quite steady strike about north 50° west and moderate northerly dip; a perfect monoclinal structure.

Second. In the belt east of this, 1 mile or more wide (on the map the central area of flat summits), the gneisses are greatly curved and twisted.

Third. In the belt extending from the previous one to the border of the schists the normal north to south strike occurs with predominating eastern dips, as in the schists.

This east and west strike and monoclinal north dip was a matter difficult of explanation, as there appeared to be a great series of gneisses and quartzites, thousands of feet in thickness, *underlying* the series of the northern part of Hoosac mountain. It was not until the white gneiss-conglomerate and schist tongue had been traced around the core of the granitoid gneiss, and it had become evident that there was an underturn of these rocks, and that they were really geologically above the granitoid gneiss, as in their normal position in the region of the tunnel, that it was possible to explain the monoclinal dip of the gneisses further south. It is now believed that this is due to a series of east-west transverse crinkles, pushed under and collapsed from the south, so that there is a constant duplication of strata in an apparent conformable series. One proof of this theory is the fact that we find the actual connection between two adjacent layers of the monoclinal series in several cases on the west brow of the mountain.

In one case a band of the gneiss having the schist both north and south of it was traced continuously along the strike for a half mile. It gradually turned to a northerly direction, the schist closely following, and then came to an end, the gneiss terminating in a small crumpled outcrop and the schist each side circling around and joining. The zone nearer the schist on the east, with general north and south strike and easterly dip, must represent a large series of similar north and south folds overturned to the west, and the areas of extremely crumpled gneiss between the two represent the turning point where the east and west folds are twisted around to the north and south direction.

In the following details the reader should refer to the map (Pl. I), on which the observations are platted. In the previous descriptions the Vermont quartzite had been followed to where the lower part passed into schistose quartzite and finally into banded white gneiss, and had been traced down to Dry brook. The upper layer of quartzite also is carried down to Dry brook and appears in massive ledges along the brook, just where it issues from the mountain. It is quarried here in a sand mine and runs up the brook several hundred feet in great ledges, striking north 35° west, dip northeast 25°. In one place, a few feet west of the sand mine, the quartzite forms an iron breccia, which is evidence of crushing. From the sand quarry this quartzite can be traced along the strike for a quarter of a mile into the region of the gneiss. At first it forms a massive quartzite in bluffs; then bands of micaceous gneiss come in; and there are alternating layers a foot or two wide of pure quartzite and layers of finely banded white gneiss. These changes are well shown in this distance. The transition from quartzite to gneiss is unmistakable and plainly to be followed. There are ledges of rock here which have elongated pebbles resembling the conglomerate. For a mile north we have a series of fine-grained, banded white gneisses, with steady strike north 40° to 50° west and northerly dip, which on the west slopes of the mountain towards the valley are greatly contorted, the layers of the monocline doubling on themselves and running back in a manner which it would be impossible to describe in detail.

At a point a mile north of Dry brook, just on the west edge of the mountain, we find a large bluff of gneissoid conglomerate, the flattened pebbles composed of quartz grains, while muscovite and biotite plates and some feldspar, with octahedra of magnetite form the cement—a gneiss. The rock is often banded, bands of mica-schist alternating with those of conglomerate. The ledge strikes north 40° west and dips 40° northerly. The continuation of this series of rocks can be traced over a mile southeast with about the same strike and dip. This bluff is on the west crest of the mountain. When we go north from this outcrop we can trace this series of conglomerates within a space of about a quarter of a mile to outcrops with northeast strike and steep northerly dip, then east and west strike with northerly dip, and then the same original strike north 40° west, dip northeast, with which we started; the rock then strikes southeast into the gneiss area of the Hoosac mountain, where its character is lost. Thus we have here the case of two layers of the monoclinal series joining to form one double band, the connection made by a series of curving layers at the west edge of the mountain. This conglomerate is bounded on the west by beds of massive quartzite which can be traced by loose pieces along the mountain side nearly to Dry brook, where they connect with the quartzite of the sand quarry. By what complicated crumpling this is effected it is difficult to say.

In the little brook running west down the side of the mountain, about midway between Dry brook and the turn of the mountain, we have an important contact between the schist (forming the large area in the valley) and the (Vermont) quartzite of the side of the mountain. The two rocks are conformable, strike north 35° west, dip 30° northeast. This schist extends north to the turn of the mountain, there running in east among the gneisses for some distance; it is impossible to describe the contortion it has undergone; it is in general a series of small minor folds whose axes dip northerly with the dip of the strata. The line of outcrop is hence very winding and irregular. In places just here the schist assumes the form of a massive iron schist composed of quartz grains, magnetite, graphite, and biotite, which is easily followed. About half a mile south of the turn it will be noticed on the map (Pl. I) that the gneiss (Vermont) sends a curving tongue northward surrounded by schist on either side; we have in this another good proof of the real duplication of layers which causes the monoclinal dip of the gneisses. The schist and gneiss are conformable and follow each other closely to the point where curving layers of schist circle around the gneiss and cut it off. It is a very sharp anticlinal curve, the gneiss doubling back on itself with the schist closely following. (See p. 92.)

In a small brook flowing west at the point of the mountain, just below the cross roads we find again the schist in conformable contact with a quartzite which here overlies it. Both strike north 45° east and dip west gently. A few hundred feet east a quartzite white gneiss is found overlying the black modification of the schist mentioned above, which can be traced along in bluffs for nearly a mile, forming the base of the western band of white gneiss, where it has turned to run east. About a mile distant it forms locally a crumbly quartzite which has been quarried; in the intervening space we have the same phenomenon of transition of quartzite to gneiss described before near Dry brook; that is, we have small layers or lenses of the quartzite in the gneiss.

West of the contact of schist and quartzite under the bridge, the two rocks extend some hundred feet downstream; then they rise together to the bluffs and run into the open meadows, where we find outcrops of biotite-gneiss overlying the quartzite. No contact with the quartzite can be found, but the three rocks follow one another in several sharp turns, in which they seem to conform in structure. The strike turns within 300 yards from north 60° west, with northeast dip, to north 45° east, with westerly dip. This carries the rock down southeast to an outcrop along the road, where we have in place a large ledge of the quartzite-breccia indicating a sharp turn. Some hundred feet northeast an outcrop of the quartzite strikes north and south, dipping east. These outcrops are scattering, and from this point north we have a large drift-covered area with no outcrop whatever (see map, Pl. I). They are mentioned in detail because they occur in the south end of the hill in which "Burlingames" massive quartzite is found, about half a mile distant, and it seems probable that this is the same quartzite very much crumpled (corresponding to the "canoe" in which all the rocks here are folded). This enables us to connect it with "Burlingame's" quartzite and with the line of quartzite observed at intervals all the way south from the tunnel line.

We have heretofore been dealing with the boundaries of the great area of (Vermont) gneisses and quartzites between the Stockbridge limestone on the west, the Hoosac schists on the east, and the granitoid gneiss (Stamford gneiss) on the north, covering on the map parts of Windsor, Dalton, and Savoy. The attempt has not been made to determine in detail the structure of the interior of this mass, although a glance at the numerous observations on the map will show that the ground has been fairly well covered. It is impossible, so far as our work has gone, to recognize definite horizons within this mass, and without these it would be hopeless to trace out the exact structural features.

It was mentioned, in speaking of the contact of the Vermont quartzite and Stockbridge limestone, that the quartzite was succeeded by gneisses with conformable strike and easterly dip, which are often quite coarse, with blue quartz, resembling the granitoid gneiss. This feature can be noticed at several places; for instance, east of the exposure of quartzite at the extreme south end of the map. We go east for nearly a mile, finding gneisses, part coarse, part fine, and then come to massive quartzite, and well-marked conglomerate (*not* metamorphic gneiss-conglomerate), with pebbles of blue, white, and black quartz. The quartzite also circles around the eastern part of this area in Dalton (south of the limits of this map), where it is again associated with limestone. We find rather contorted gneisses in the central part of this area, under the word "Dalton" on the map, and farther north massive quartzite with north and south strike and varying dip, which is the southern continuation of that forming the sharp quartzite "points" of the mountain in Cheshire. So this part is evidently composed of numerous north to south troughs of the quartzite and conglomerate, with areas of the underlying gneiss, the quartzite covering the gneiss at both ends and being folded under it on the west.

This statement is also true of an area running south from the second point of the mountain, where the rocks are quartzite, quartz-schist, and quartzose gneisses, with beds of quartzite-conglomerate, the strike being north and south and dip steadily east.

In the region directly south of Dry brook we have coarse gneisses with blue quartz, underlying the fine grained quartzose gneisses (Vermont) which represent the quartzites, and therefore perhaps correspond to the granitoid gneiss (Stamford gneiss) of the central part of Hoosac mountain.

In Windsor we have the same series of white gneisses, the conglomerate character not marked, it being probably too far east, and the increasing metamorphism having perhaps masked the original characters.

A large part of this area is very poor in outcrops, being flat and drift-covered. We have therefore described this large region principally in reference to its boundaries, where by the contact with other rocks the true relations and structure can be determined, and we hope that our observations establish—first, the conformity of the Stockbridge limestone and Vermont quartzite, the latter underlying when in the normal position, as is shown by the contacts and lithological passage and the fact that the limestone is sharply folded with the quartzite; second, the identity of the quartzite-conglomerate horizon underlying the limestone (that is, the Vermont quartzite) with the fine grained white gneisses of the Dalton-Windsor area, and of these with the white gneiss series of the central mass of Hoosac mountain; third, the conformable contacts of the schist area in Hoosic valley with members of the quartzite-white-gneiss series.

HOOSIC VALLEY SCHIST.

We have still to take up the relations of this large schist area to the limestone. This rock is a typical schist, often garnetiferous, coming in places close to the quartzite—at the "cove" within 250 yards. Near the quartzite tongue on the western side of the "cove" we find the ground filled with loose pieces of limestone and schist, with beautiful transitions between the two rocks caused by the presence of the twinned plagioclases of the schist in the limestone (see p. 64). It may be mentioned that the same rocks occur in the beds of Mount Greylock. Only loose pieces of this transitional material occur here, with one exception, but as they are nearly on the line of contact of limestone and schist it can fairly be presumed that they are nearly in place and represent direct contact; one ledge alone is exactly in place. The contacts of this schist with the quartzites of the white gneiss series have been mentioned; in one case the schist underlies, in the other overlies. In the former case, near the large "canoe," we know that the white gneiss series is inverted; in the other we know that it must be normal, and hence the position of the schist as overlying the quartzite-gneiss is made clear. The Stockbridge limestone bounds this schist on the west and northwest. At the southwest corner no contact is found, although the two rocks come quite close together, the schist forming a hill, the limestone lying in the valley at its base. The contact (concealed) runs along to Cheshire Harbor, where limestone and schist are within 20 feet horizontally. The two rocks have the same strike, north 35° east. The dip of the limestone is 30° westerly; that of the schist is obscure, but appears to be westerly. This seems, therefore, to be a conformable juxtaposition, although actual contact is wanting. The line of contact runs north for a mile, then doubles around the north ridge of the schist and runs southeast. Where it crosses Dry brook we find massive limestone within a few feet of the schist, and the limestone seems to dip under the schist. There is also exposed in the brook, near the contact, interbanded limestone and schist near the contact of both rocks, just as observed in North Adams (see p. 88). The line of contact just here is very irregular, zigzagging, as we should expect in these crumpled, sharply folded rocks. At the south end of the lenticular hill north of Dry brook the outcrops disappear for over a mile, when we come to Tophet brook, where we have the gneiss, quartzite, and limestone in close contact, as previously described. From here north to the locality in North Adams described (p. 88) the contact of the limestone is concealed on the east, although in places very close. The structure is given on the map (Pl. I and IV) by strikes and dips. North of the North Adams locality no limestone in place has been discovered. The head of the valley containing the north fork of the Hoosic river, some 8 or 9 miles from North Adams, is formed by the schists of the northern part of Hoosac mountain. The limestone evidently runs up for some distance from North Adams, covered with drift, and then disappears.

THE REGION AROUND CLARKSBURG MOUNTAIN AND STAMFORD, VERMONT.

This brings us to the last area to be described in this report, namely, the mass of Clarksburg mountain, northeast of Williamstown and northwest of North Adams. As will be seen by the map, the north and south forks of Hoosic river unite at North Adams and flow due west through an east to west valley, lying between the north end of the Greylock mass and the south slopes of a high mountain mass extending down from Stamford, Vermont, into the town of Clarksburg, Massachusetts.

We find the Stockbridge limestone in the streets of North Adams (see map, Pl. I) and in the high ridge just south of the railroad, where it is found in contact with and overlying the Mount Greylock Berkshire schist. The latter rock is cut through by a railroad tunnel just west of the North Adams depot, where the limestone forms part of the eastern side of the Greylock synclinorium, really underlying the Berkshire schist, but here inverted by a sharp, overturned fold.

The summit of Clarksburg mountain is composed of a mass of granitoid gneiss (Stamford gneiss) identical in petrographic characters with that of the Hoosac tunnel (Stamford granite). This is overlain by the Clarksburg quartzite (Vermont formation) on the west and south sides, and by quartzites and gneisses on the east side, the contacts having been found. In this quartzite Mr. Walcott has found the remains of trilobites, making it Lower Cambrian, and we shall now endeavor to show that this is represented by the gneiss found on the east side of the mountain.

Near the old signal station on Clarksburg mountain, the quartzite is represented at the immediate contact by a blue quartz pebble conglomerate, quite micaceous, the pebbles composed of aggregate quartz. Some distance above the contact the quartzite contains beds of a quartz schist of considerable thickness. The quartzite and conglomerate are found within 2 or 3 feet of strata of each other, the quartzite striking on the average about north 33° west, and dipping 25° southwest. The granitoid gneiss in part has little structure, but in several places this feature is well marked by the mica planes, which are in general parallel both in strike and dip to those of the quartzite, so that in so far as we can accept as stratification such structural planes in the gneiss, the two rocks are parallel. From this place, on the northwest edge of the mountain, the line of contact, curving gently, runs to the southeast brow of the mountain above North Adams, where it turns and strikes northeast. The contact here between the two rocks is very close, and the structure of the granitoid gneiss obscure. The rock is massive. The quartzite strikes north 30° east, dips 40° southeast. The line of contact across the mountain can be traced in a general way, but no outcrops near together have been found.

The whole south slope of the mountain down to the valley is covered with the quartzite and the interbanded quartz schist. The southwest dip is well marked above Williamstown, while on the North Adams side it is southeast. This mountain is a large quartzite dome, doubtless with many minor crumples. This quartzite is found as low down as the river bank opposite the cemetery in North Adams. It is last seen in contact with the granitoid gneiss at the place mentioned above, but it is thence eroded away to the north for a distance of 2½ miles, in which drift covers the valley and lower slopes of the mountain, the granitoid gneiss occupying the crest.

Just north of the Massachusetts state line, in Vermont, about $2\frac{1}{2}$ miles northeast of the last contact, we find again the contact of the granitoid gneiss with quartzite; this is in Stamford, in the hills west of the village.[1]

The granitoid gneiss has the same general characters that it has further south. The contact is found near an old schoolhouse along the roadside. The quartzite is micaceous and strikes north 30° to 55° east, being curved a little in the outcrop and dipping 42° east; the contact is seen here within

FIG. 28.—Contact of granitoid gneiss (Stamford gneiss) and quartzite (Vermont formation), Stamford, Vt. Looking north.

The gneiss fills the left half of the figure. It is here very coarse, with structure feebly indicated. The hollow in its center (through which the road goes) is caused by the erosion of a vertical dike of amphibolite about 11 feet wide, which does not penetrate the q uartzite. The quartzite is seen on the right, dipping southeast.

1 foot of strata, and by digging the actual contact was found. The lamination of the granitoid gneiss strikes north 55° east, dips about 40° easterly; that is, in a general way conformable to the bedding of the quartzite. At this place a vertical band of rock 14 feet wide strikes north 60° west, or across the strike of both rocks; it has the character of the altered rocks described on pages 65 to 69 and is undoubtedly a dike; this runs in a straight line through the granitoid gneiss, but abuts against the quartzite

[1] C. H. Hitchcock briefly describes this locality in Geology of Vermont, p. 601.

without passing into it, and the quartzite has a curious thickening of its layers where the dike joins it, as though there had been a hollow, owing to erosion of the dike before deposition of quartzite. It seems therefore to show the most perfect unconformity between the granitoid gneiss and the overlying quartzite, although the lines of structure of both rocks are parallel. (See Figs. 28 and 29.) We can trace this contact northward for a quarter of a mile or more; the quartzite is interbanded with very feldspathic gneisses, the whole forming quite a thick series. The rocks dip east (43° east, strike

Fig. 29.—Contact of granitoid gneiss and quartzite; same locality as 28, looking east, showing the quartzite nearer. The dike was found, by digging, to lie against the quartzite without passing into it, and the quartzite shows a curious lenticular thickening just in the line of the dike, as though there had been a depression there at the time of deposit.

north 40° east) and so does the structure of the granitoid gneiss. Between this point and the quartzite above North Adams one outcrop of quartzite conglomerate has been found in place, strike north 45° east, dip 30° east. There seems therefore no doubt that this series of quartzites and gneisses, lying on the granitoid gneiss without a fault, are the same as the quartzite at North Adams, 2 miles off: they have the same strike and dip and lie on the same rock, and a glance at the map will show that the line of strike runs from one to the other. We have here then the second proof that the white gneiss-conglomerate of Hoosac mountain is the Cambrian quartzite (Vermont).

GENERAL CONCLUSIONS.

In the previous pages a presentation of the facts observed has been attempted without drawing conclusions or stating results. A brief summary is therefore here introduced.

The rocks of Hoosac mountain consist of quartzites, conglomerates, gneisses, limestones, schists, and amphibolites. In all these rocks there is abundant evidence that some elements have been crushed by great pressure; the large broken microcline and quartz masses of the coarse gneiss and the pebbles of the conglomerate show this, and this crushing has been accompanied by chemical action which has formed new feldspar, mica, and quartz. With the exception of the pebbles of the conglomerates, it is with great difficulty that we recognize the remains of detrital material, and yet a large part of the series is of detrital origin. The rocks as we now find them are thoroughly metamorphic, and yet we feel sure that the material for the present rocks must have come from the old sediments. To trace the process of change is a problem of the future. If, as this work indicates, these rocks are simply the Cambrian and Silurian sandstones, limestones, and shales, altered by a metamorphism increasing from the Hudson river eastward, then careful petrographic studies along an east to west line ought to solve this problem. A partial investigation of some of the rocks of Mount Greylock, made by the writer, shows the great similarity between the metamorphic rocks of Hoosac mountain and of Greylock, qualitatively considered, but in quantity the difference is striking. There are no coarse gneisses on Greylock, and it is only locally that fine-grained banded gneisses are found, but limestones, quartzites, and schists (or phyllites) abound, and we must again state the absolute lithologic identity of these varieties with those of Hoosac. The schists of Mount Greylock and of the Taconic range have the same crystals of albite and the same ottrelite; the limestone of Greylock is feldspathic, just like that at the base of Hoosac. It is then a suggestion worth considering whether the metamorphism does not increase as we go downward as well as eastward. The schists of Greylock and those of Hoosac at the top of the series are alike; the coarse gneisses at the base of the Hoosac series are not found in Mount Greylock or in the Taconic range, at least not here. I am not prepared to say that the granitoid gneiss itself might not be an altered sediment, instead of an eruptive granite affected by dynamic metamorphism, but in such an extreme case we need careful proof of the process of change, which we can not yet give. This rock has perhaps rightly been called Archean by J. D. Dana, C. H. Hitchcock, C. D. Walcott, and others, the proof resting on some lithological resemblance or on unconformity with the overlying rock. It has been shown in the previous pages that this evidence is unsatisfactory, for the most absolute conformity exists in places, and the overlying rocks sometimes take on the characters of the granitoid gneiss. The altered trap dike found in Stamford, which cuts the granitoid gneiss but not the quartzite, is the first conclusive evidence of nonconformity.

Another striking fact is the uniform result produced by metamorphism in the originally dissimilar rocks. The amphibolites were primarily trap rocks composed of hornblende and feldspar, and even the hornblende may have been derived from augite and the rock a diabase; but this fact, proved for rocks in other regions, is yet in doubt here. By the metamorphism of these eruptive rocks new feldspar, biotite, hornblende, etc., are formed—of which minerals some occur with the same peculiar features (feldspar) in the schists which have been formed from sediments (shales, slates, etc.). In the process of metamorphism here there must have been an important chemical action originating from without the rocks.

A further unexplained condition is the vertical position of the plane of lithologic change toward a gneissic character. The fossiliferous Cambrian quartzite (Vermont) of Clarksburg mountain forms a great dome, on the east side of which it strikes northeast toward the crystalline rocks, and within 2 miles, in Stamford, Vt., we find it partially changed to gneisses. The quartzite of Cheshire preserves its character as quartzite until its strike carries it east across a certain meridian (the west crest of Hoosac mountain), then in a quarter of a mile, passing this line, it gradually changes into a white gneiss by taking up feldspar and mica. A mile or so north we find that the ends of the little cross-crinkles in the white gneiss north of Dry brook are quartzite and ordinary quartzite-conglomerate. They pass into white gneiss when they strike east within a very short distance.

Lastly, there is the limestone which on Greylock underlies and is interstratified with the schists; we find this in Hoosic valley close to the gneiss and quartzites, but no sign of it on the mountain proper. Reviewing the evidence bearing on the position of the limestone, we have on Hoosac mountain a conformable series—granitoid gneiss, overlain by a white-gneiss-conglomerate-quartzite formation, and this by schist. We trace along the strike the quartzite of Hoosic valley into this white gneiss-conglomerate-quartzite series underlying the schists; and we also trace the same Cambrian quartzite of Clarksburg mountain into white gneisses. This quartzite of Hoosic valley we find in several localities passing upward into the limestone; it is Prof. Dana's quartz rock which underlies the limestone. This quartzite we trace also laterally into the Hoosac mountain white gneisses, and we find the schist which borders the limestone of Hoosic valley in several conformable contacts with the mountain quartzites and white gneisses with no intervening limestone. We find near the contact of schist and limestone perfect transitional feldspathic micaceous limestones (not all in place) and near North Adams very close proximity of the schist belonging to Hoosac mountain with limestone. There seeems to be conformity between all the rocks, and yet the limestone is wanting in the mountain section. The only solution would seem to be that the limestone is replaced by the schist on the other side of the line or plane mentioned above, whether it be an original shore line, or some bounding line or plane of certain conditions of metamorphism peculiar to the axis of the Green mountains. To bring in a fault or thrust plane at the base of the Hoosac mountain, cutting off the crystalline rocks of the Green mountains from the fossiliferous rocks west, is an easy solution of a difficult problem, but not the correct one if the facts are correctly interpreted.[1]

There remain to summarize the facts bearing on the stratigraphy of Hoosac mountain. The reasons for the conclusions as to the general structure of Hoosac mountain need not be recapitulated here; it is an anticlinal fold, the axis of which lies nearly in the meridian. This axis is not horizontal, but inclines or "pitches" (to borrow a term used for similar folds in the New

[1] The reader is referred to Part I for a further discussion of the condition of the Hoosac and Greylock columns.

Jersey iron ores) 10° to 15° to the north. It is this pitch which enables us to get the series of rocks in normal position and measure their thickness, just on the axis of the fold, for on the sides we could never have known which rock was the upper or the lower, owing to inversions, or whether the apparent thickness was not produced by duplication of a thin layer by frequent closed and overturned folds, as is the case at the southern end of the field.

This anticline preserves the rocks in their normal position on the east side, but on the west they are folded under in inverse position, with eastern dip. (See Profile v[a], Pl. vi). It is also proved that at the south end the rocks have been pushed in under, so that they dip north instead of south, as they would naturally do if the fold terminated in another dome at its south end. Where the normal east side of the anticline and the underturned west and south sides meet we find a great crumpling, and then the two sides come together and the whole series strikes north to south. The long, thin tongue of schist which runs south from the main mass is conformable to the gneisses on both sides of it, and must therefore lie in a narrow trough in the white gneisses which terminates at the south end. The second or west band of gneisses, judging from its conformity to the schist and from the fact that it runs into the larger area of gneiss as one of the series, after the schist tongue ends, must be considered identical with the gneiss next to the granitoid gneiss, except that in this western band it has more of the quartzite and less of the gneiss character, corresponding to the general change across this meridian. This western band would in that case represent an overturned anticline in the white gneiss, really overlain by the limestone, which by the overturn is made to dip under it. This anticlinal trough of white gneiss pitches under the schist north of the tunnel. Lastly, if the limestone and schist are the same rock we must suppose that the change from one to the other took place in the eroded portion of the arch which connected the limestone with the trough of schist. Profile v[a], Pl. vi, illustrates this theory. I am well aware that such an explanation seems forced. It would be much more plausible to say that these formations are separated by north to south faults, but all the evidence goes against the existence of faults. Where formations are found to overlie each other conformably at so many points and to curve around in conformity, as at the southwest corner of Hoosac mountain, no kind of fault could explain the relations. In fact, faults on a large scale seem to be absent, although considerable breaking may have accompanied the great crumpling. On the summit of the mountain east of Berkshire, near the extreme southern end of the map, a small fault was found between quartzite and schist. The relation of the rocks at the west end of the tunnel is of much more importance and the explanation not easy without assuming a fault. It will be noticed by Profile III, Pl. V, that the west edge of the trough of schist which runs along the west slope of the mountain lies at the tunnel level, considerably west of its position at the surface, so that the band of white gneiss lying in the tunnel west of the schist seems to lie on top of it at the surface. It should be remembered that this band of schist and gneiss west of it have been traced many miles side by side to the south point of the great fold, where they curve together to the east and are found in conformable contact and even transition with each other. It is therefore impossible to explain their general relations by a fault, but there may be a fault separating them for a short distance here or else an overturned fold in the western gneiss curving far back to the east, like the great Glarus fold.[1] It would be impossible fully to explain by words the structure of the east to west striking gneisses just south of the west corner of the main fold. If a piece of cloth is worked into a number of parallel folds or plaits and one-half of the cloth bent around at right angles to the former general trend of the plaits, we get just the series of transverse folds which exist on the mountain. The sections of the Alps given by Heim show folding of equal complication in younger rocks. A model would be the proper means of representing this structure.

One result of this work important to future investigation in the regions of crystalline rocks is that it shows the possibility, by proper methods of work, of determining much of the stratigraphy of these rocks, improbable as it may seem at first sight. The gneisses of the Green mountains are just as susceptible to stratigraphic investigation as the unaltered sediments of the Appalachians, but the problem is much more difficult owing to the secondary structures produced by metamorphism.

[1] Heim, "Mechanismus der Gebirgsbildung."

In the preceding pages of this chapter no reference has been made to earlier work in this area, because the little recorded is largely based on a general survey of the Green mountains and no attempt has been made to master the local structure in detail.

Most geological workers have given their attention to the limestone and schists west of the axial range. Prof. J. D. Dana, who has devoted so many years of his life to the Taconic question, has published no decided opinion on the Hoosac tunnel series. The geological sections of President Hitchcock and Prof. C. H. Hitchcock,[1] which cross this area, are not sufficiently detailed for comparison in this connection.

Ebenezer Emmons alludes to Hoosac mountain in his "Taconic System."[2] He considers that the Hoosac mountain schists were primary and that the lower Taconic rocks (Mount Greylock) were derived from them—a theory by which he explains the close lithological similarity which he had observed between the two rocks. It is evident how inadequate this theory is to explain this resemblance when we remember that in the albite schist, for instance, common to both series, the albite crystals are metamorphic in both rocks.

Emmons also describes (p. 120) the contact of conglomerate and gneiss on Clarksburg mountain, north of Williamstown.

President E. Hitchcock[3] regards as primary the Hoosac mountain limestones at the base and part of the rocks further west. He also speaks of the transitions between quartzite and gneiss.

Prof. C. H. Hitchcock[4] places a fault between the limestone at the west portal of the tunnel and the Hoosac mountain gneiss.

In the writings of Prof. J. D. Dana on the Taconic rocks there are a few allusions to the Hoosac mountain region. He speaks of the Stamford granite as "an undoubted Archean area,"[5] but this seems to be based on lithological characters. He says,[6] "there is some reason for making Hoosac mountain Cambrian."

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[1] Geology of Massachusetts, 1841. Geology of Vermont, 1861.
[2] Agricultural Report, New York, p. 53.
[3] Final Report, Geology of Massachusetts. p. 577 *et seq.*
[4] Geology of Vermont, p. 597.
[5] Amer. Jour. Sci., vol. 33, 1887, p. 274.
[6] Ibid., p. 410.

No detailed geological study of the Hoosac tunnel seems to have been published, which is remarkable considering the importance of this engineering work and the number of experts who examined it when in construction.

In the reports of Profs. James Hall and T. Sterry Hunt as experts[1] the general distribution of the rocks in the tunnel is correctly given. Prof. Hall noticed the transition from white gneiss to granitoid gneiss at the west edge of the latter rock, and also speaks of the micaceous gneiss at the west portal "resting against or upon the limestone," an exposure no longer visible.

[1] Massachusetts House Document No. 9, January, 1875, Appendix.

PLATE VII.

PLATE VII.

A. Fine grained white gneiss (Vermont formation) from western slope Hoosac mountain. From a microphotograph. Polarized light, × 33.

In the large feldspar twin *a*, the line of twinning is oblique to the external planes of the crystal. The little black or white round spots in it are grains of quartz which lie roughly in lines parallel to the lines of arrangement of the quartz, feldspar, and mica outside.

B. Gneiss (Vermont formation). Dump Hoosac tunnel. From a microphotograph. Polarized light, × 33.

A large crystal of microcline (*a*) has been broken into five parts in the general crushing of the rock, and the groundmass, composed of little grains of quartz and feldspar and some mica, crosses it by the cracks.

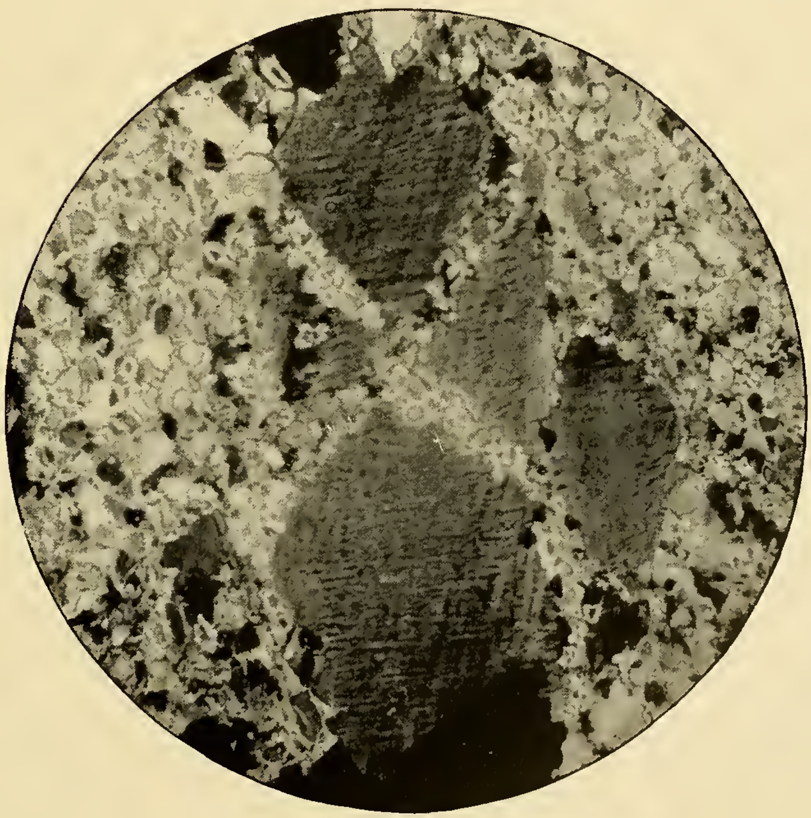
A

B

A

B

A



B

THIN SECTIONS, WHITE GNEISS.

PLATE VIII.

111

PLATE VIII.

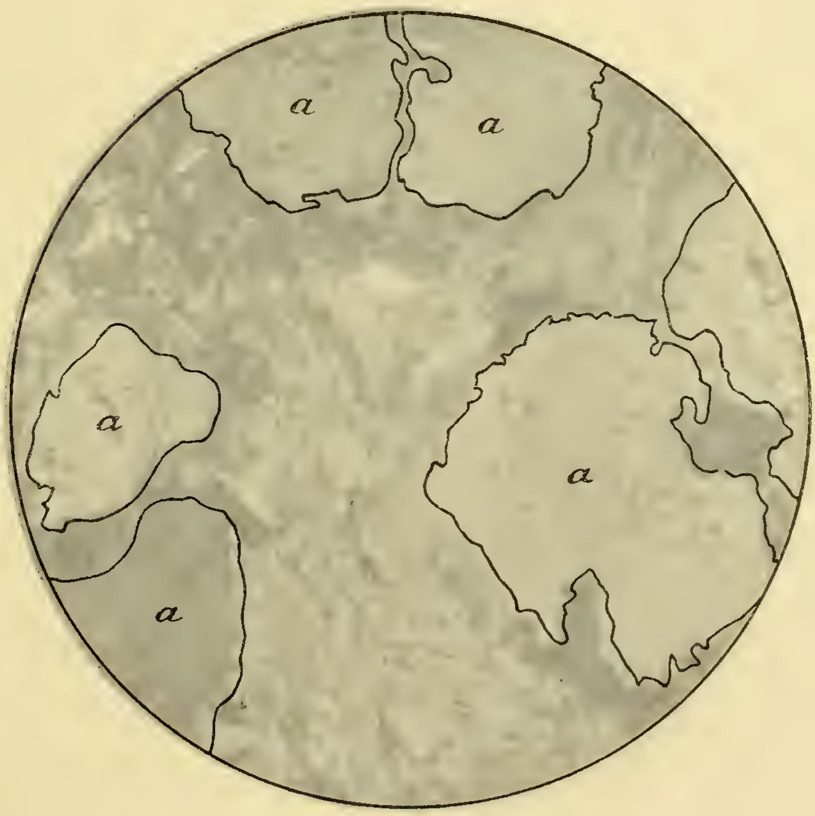
A. Fine grained white gneiss (Vermont formation). Hoosac mountain. Microphotograph. Polarized light, × 33.

Porphyritic feldspar twin (*a*) containing inclusions of quartz and mica which are arranged parallel to the minerals of the groundmass outside.

B. Albite schist (Hoosac schist). Hoosac mountain. Microphotograph. × 33.

The large crystals of albite (*a*) contain inclusions of muscovite, chlorite, magnetite, and quartz. The gentle curving of the mica of the groundmass between these feldspars is well shown.

A



B

PLATE VIII

A. [illegible] ar[illegible]

Porphyriti[illegible] twin [illegible] containing [illegible] and [illegible] which are arranged [illegible]

B. [illegible]

T[illegible] magnetite, a[illegible] qua[illegible] [illegible] feldspars [illegible] well shown.

112

A

B

A

B

THIN SECTIONS, WHITE GNEISS AND ALBITE-SCHIST.

PLATE IX.

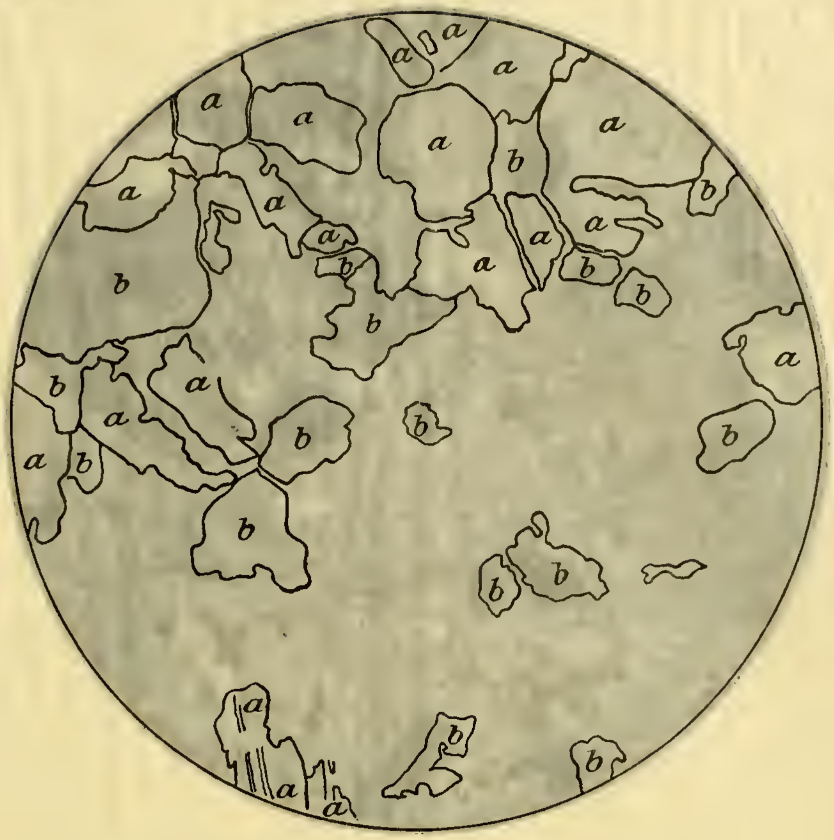
PLATE IX.

A. "Amphibolite." Diorite dike. Hoosac mountain, south of Cheshire. Microphotograph, × 33.

Crystalloids or grains of plagioclase feldspar (*a*) and of brown hornblende (*b*) are seen around the edge of the figure. In the center we have an aggregate of irregular patches of secondary feldspar, green hornblende, epidote, etc., forming a confused aggregate, little veins of which are seen to penetrate the feldspars or pass between them.

B. Amphibolite. Mount Holly, Vermont. Microphotograph; polarized light × 33.

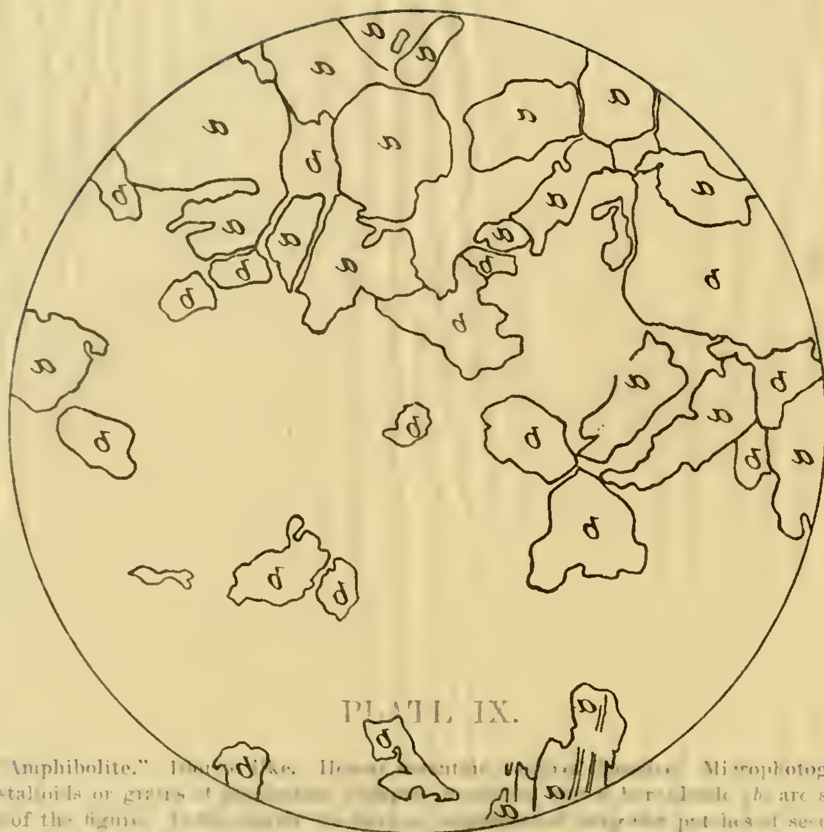
The large black areas are a deep greenish-brown hornblende, surrounded by a fringe of light green hornblende. This shows best in the crystal in the center (*a*) with the fringe (*b*). The portion between the black crystals is an aggregate of epidote prisms, masses of green hornblende, and feldspar.



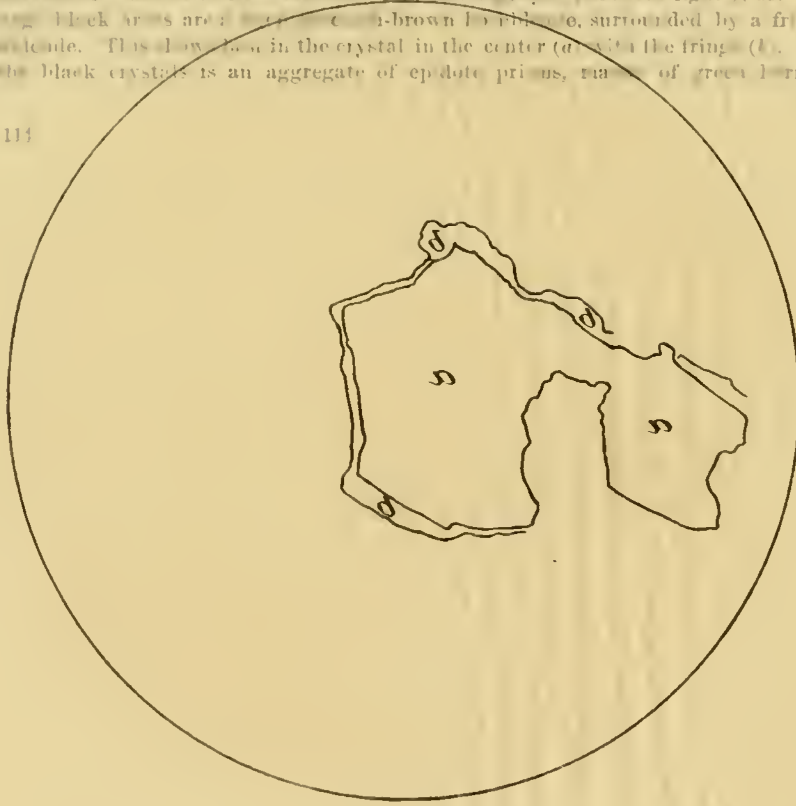
A

B

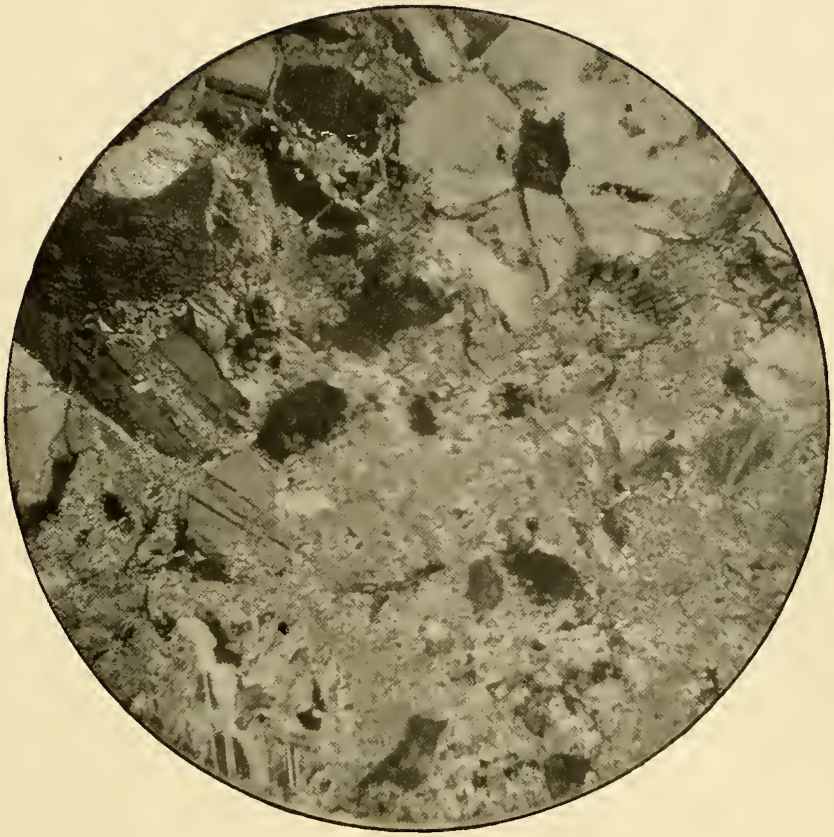
THIN SECTIONS DIO[illegible] AN[illegible] [illegible]ITE



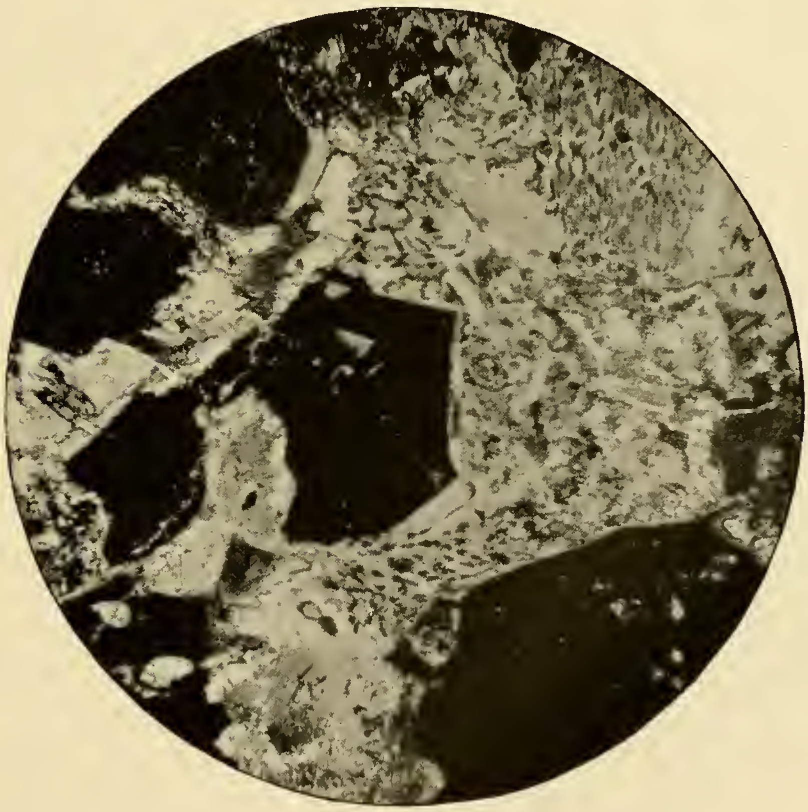
A



B



A



B

THIN SECTIONS, DIORITE AND AMPHIBOLITE.

PLATE X.

115

PLATE X.

A. Quartzite-conglomerate (Vermont formation). Stone hill, Williamstown, Mass. Microphotograph; polarized light, × 27.

The shadowy area filling the left half is one of the masses of crushed blue quartz which shows the so-called "wavy" extinction in polarized light. At the top it is seen passing into the quartz mosaic of the "groundmass." At the bottom and lower right side a crystal of microcline has been faulted several times and the fine quartz of the groundmass penetrates it.

B. Crumpled metamorphic conglomerate (Vermont formation). Hoosac mountain, bluffs south of Spruce hill, near that of Fig. 17. About one-eighteenth natural size.

These pebbles are granulitic and by pressure have been gently crumpled. This figure represents the transitional form between the conglomerate and the white gneiss; in the latter the granulitic lenses remind us of pebbles, but they have lost their shape.

A

B

QUARTZITE CONGLOMERATE AND CRUMPLED METAMORPHIC CONGLOMERATE.

PLATE XI.

PLATE XI.

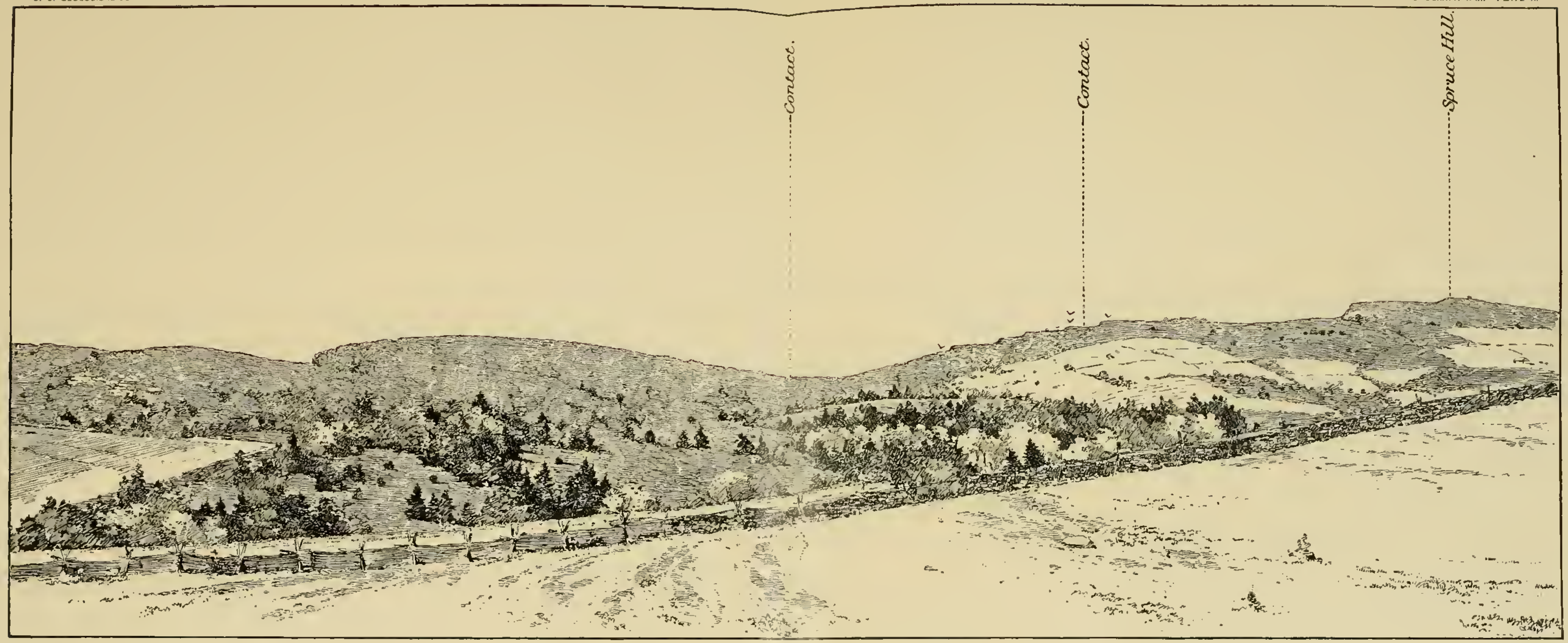
A. Looking north over the crest of Hoosac mountain from the northern end of the granitoid gneiss (compare Pl. V., Profile IX), showing the outcropping edges of the northerly dipping (pitching) beds of conglomerate gneiss and albite schist. From a drawing by Josiah Pierce, jr.

B. Profile of Hoosac mountain from Spruce hill southward, looking west.

This includes the contact of all three formations—granitoid gneiss (Stamford gneiss), conglomerate (Vermont gneiss), and albite schist (Hoosac schist). The northerly pitch of the axis and consequent overlay of the formations to the north shows plainly in the long gentle northward slope and sharp bluffs to the south. The rounded granite topography of the coarse gneiss is also in marked contrast with the serrations produced by conglomerate and schist. Cf. Plate V, Profiles IX and X.

ERRATUM.

PLATE XI.—Legends to Figs. A and B should be transposed.



A. VIEW NORTH OVER CREST OF HOOSAC MOUNTAIN.

B. PROFILE OF HOOSAC MOUNTAIN FROM SPRUCE HILL SOUTHWARD, LOOKING WEST.

PART III.

MOUNT GREYLOCK:

ITS AREAL AND STRUCTURAL GEOLOGY.

By T. NELSON DALE.

CONTENTS.

ILLUSTRATIONS.

OUTLINE OF THIS PAPER.

Mount Greylock, or Saddle mountain, in northwestern Massachusetts, has been studied off and on by geologists for seventy years. The literature is given on p. 131. The general synclinal structure of the mountain is well known. This description is based upon the new topographic map of the U. S. Geological Survey, and upon the results of recent orographic science. Mr. J. Eliot Wolff has done the petrographic work.

The mountain consists mainly of one central and two lateral subordinate ridges, all trending about north-northeast to south-southwest. With its spurs it forms a topographic unit and measures 16½ miles in length and averages about 3¼ in width. Its aspects from the north, south, east, and west are described on p. 134 (Pls. XII, XIII–XV). The "saddle" is formed by a depression in the southwesterly bend of the central ridge, between Greylock summit (3,505 feet) on the north and Saddle Ball (3,300 feet) on the south. These are about 2 miles apart, and the lowest part of the saddle is 605 feet lower than Greylock summit.

Structural.—The rocks are all metamorphic and of few kinds, crystalline limestone, quartzite, and schists. The key to the structure is in the distinction between cleavage foliation and stratification foliation. The principal recent and older literature of that subject is given on p. 137. The phenomena of cleavage and stratification and pitch, as they occur on Greylock, are illustrated by ten typical cases. These lead to the adoption of the following structural principles: I. Lamination in the schist or the limestone may be either stratification foliation or cleavage foliation or both, or sometimes, in limestone at least, "false bedding." To establish conformability, the conformability of the stratification foliation must be shown. II. Stratification foliation is indicated by: (*a*) the course of minute but visible plications; (*b*) the course of the microscopic plications; (*c*) the general course of the quartz laminæ whenever they can be clearly distinguished from those which lie in the cleavage planes. III. Cleavage foliation may consist of: (*a*) planes produced by or coincident with the faulted limbs of the minute plications; (*b*) planes of fracture, resembling joints on a very minute scale, with or without faulting of the plications; (*c*) a cleavage approaching slaty cleavage, in which the axes of all the particles have assumed either the direction of the cleavage or one forming a very acute angle to it, and where stratification foliation is no longer visible. IV. A secondary cleavage, resembling a minute jointing, occurs in scattered localities. V. The degree and direction of the pitch of a fold are often indicated by those of the axes of the minor plications on its sides. VI. The strikes of the stratification foliation and cleavage foliation often differ in the same rock, and are then regarded as indicating a pitching fold. VII. Such a correspondence exists between the stratification and cleavage foliations of the great folds and those of the minute plications that a very small specimen properly oriented gives, in many cases, the key to the structure over a large portion of the side of a fold.

On these principles twelve complete and three partial transverse sections have been constructed across the Greylock mass (Pls. XVIII–XXII). These show that the range consists of a series of more or less open or compressed synclines and anticlines, which, beginning near North Adams, increase southerly in number and altitude with the increasing width and altitude of the schist area, and then, from a point about a mile and a half south of the summit, begin to widen out, and to diminish in number and height until they finally pass into a few broad and low undulations west of Cheshire. Between that point and the villages of Berkshire and Lanesboro the folds become sharper and more compressed, and the schist area rapidly narrows, terminating within a short distance of Pittsfield. The two most comprehensive and best substantiated of these sections (G and I) begin near South Adams, cross the central ridge north and south of the summit, then follow the two great western spurs, and end near South Williamstown. The sections are described on p. 160, the first two in some detail. The section lines on the map (Pl. I) and the epitomized sections in Fig. 72 on p. 178 show the relations of the fifteen sections to each other.

Résumé, structural.—Mount Greylock with its subordinate ridges is a synclinorium consisting in its broadest portion of ten or eleven synclines alternating with as many anticlines. While the number of these minor synclines is so considerable at the surface, in carrying the sections downward they resolve themselves chiefly into two great synclines with several lateral and minor ones. The larger of these two forms the central ridge of the mass; the smaller one, east of it, forms Ragged mountain and an inner line of foot-hills farther south. The anticline between these coincides with the Bellowspipe notch; that on the west of the central syncline is on the west side of the north-south part of the Hopper. The major and central syncline is so compressed east of Symonds peak (Mount Prospect) and Bald mountain, and its axial plane is so inclined to the east that the calcareous strata which underlie the central ridge have on its west side a westerly dip. Farther south this syncline opens out, and all the relations become more normal. On either side of those two main synclines the subordinate folds are more or less open and have their axial planes vertical or inclined east or west. The long undulations in the axes of these synclines are shown in four longitudinal sections (Pl. XXIII): Section P, the eastern or Ragged mountain syncline; Q, the central or Greylock syncline, and R′ R″, portions of two of the minor synclines on the west flank of the mass. In each of the sections P and Q the trough bottom deepens at two points. In the eastern syncline, P, the deeper part of the northern depression is shown to be about under the center of Ragged mountain, while in the central one, Q, the deeper part of the northern depression seems to be about 2 miles farther south, between Greylock and Saddle Ball and near Greylock summit. The northern side or edge of this great double trough is at the extreme north end of the Greylock mass; section Q begins at Clarksburg mountain, and its southern edge is between 7½ and 8½ miles distant, near Round Rocks and on the southeast spur of Saddle Ball. South of these main troughs is another pair, the centers of which lie west of Cheshire reservoir. To the west of these two long axes the mountain mass is made up of numerous minor folds, which do not show the continuity seen in P and Q. It will be seen that the direction of these two main synclines represented by P and Q is north-northeast by south-southwest, thus nearly parallel with the direction of the valley lying between the Clarksburg granitoid gneiss mass and Hoosac mountain, and that at the south end they converge and perhaps unite in the narrow schist ridge between Berkshire and Lanesboro villages. Traversing the folds of this canoe-like complex synclinorium is a cleavage foliation, sometimes microscopically minute, dipping almost uniformly east. This cleavage foliation is distinct from the "slaty cleavage," early described by Sedgwick, Sharpe, and Sorby and reproduced experimentally by Tyndall and Jannettaz, and consists sometimes of a minute, abrupt, joint-like fracturing of the stratification laminæ, but more usually of a faulting of these laminæ as the result of their extreme plication—a mode of cleavage ("Ausweichungsclivage") so well described by Heim and recently reproduced in part by Cadell by a slight modification of the experiments made by Prof. Alphonse Favre, of Geneva, in 1878. (See foot-notes, p. 137.) This slip cleavage, when carried to its extreme, results in a form of cleavage very much approaching, although not identical with, slaty cleavage. To the unaided eye all traces of stratification are lost, and even under the microscope they are so nearly lost as to be of no avail in determining the dip. This and the regular slip cleavage often occur in close proximity.

Lithologic stratigraphy.—There are five more or less distinct horizons in the Greylock mass. The following descriptions are based upon Mr. Wolff's petrographic determinations, beginning above:

The Greylock schist (*Sg*). Muscovite (sericite), chlorite, and quartz schist, with or without biotite, albite, magnetite, tabular crystals of interleaved ilmenite and chlorite, ottrelite, microscopic rutile, and tourmaline. Thickness, 1,500 to 2,200 feet. Part of Emmons's pre-Cambrian or Lower Taconic No. 3 ("talcose slate"), Walcott's Hudson River (Lower Silurian).

Bellowspipe limestone (*Sbp*). Limestone more or less crystalline, generally micaceous or pyritiferous, passing into a calcareous schist or a feldspathic quartzite, or a fine-grained gneiss with zircon and microcline, in places a noncalcareous schist. The more common minerals are graphite, pyrite, albite, microscopic rutile, and tourmaline; rarely, galena and zinc blende. Thickness, 600 to 700 feet. Part of Emmons's pre-Cambrian or Lower Taconic No. 3 ("talcose slate"), Walcott's Hudson River (Lower Silurian).

The Berkshire schist (*Sb*). Schist like the Greylock schist, but more frequently calcareous and plumbaginous, especially toward the underlying limestone (€Ss); thickness, 1,000 to 2,000 feet. Part of Emmons's pre-Cambrian or Lower Taconic No. 3 ("talcose slate"), Walcott's Hudson River (Lower Silurian).

The Stockbridge limestone (*€Ss*). Limestone, crystalline, in places a dolomite, quartzose or micaceous, more rarely feldspathic, very rarely fossiliferous. Galena and zinc blende rare. Irregular masses of iron ore (limonite) associated sometimes with manganese ore (pyrolusite). Thickness 1,200 to 1,400 feet. Emmons's pre-Cambrian or Lower Taconic No. 2 ("Stockbridge limestone"), Walcott's Hudson River (Lower Silurian).

The Vermont formation (*€v*). Quartzite, cropping out in the Greylock area only once, but probably underlying the entire mass. Thickness, 800 to 900 feet, Emmons's pre-Cambrian or Lower Taconic No. 1 ("granular quartz"), Walcott's "*Olenellus*" (Lower Cambrian). Total thickness of the series, 5,000 to 7,200 feet.

The estimates of thickness are based upon the sections. The difference in the estimates arises partly from the varying amount of thickening in plication. The actual thickness is probably less than the minimum figures given above, and possibly much less. The maximum thickness of the entire series does not exceed the minimum thickness attributed to the Lower Silurian in the Appalachian region. See page 190 for a tabular arrangement of these results.

Areal geology.—The accompanying geographic map of Greylock and the adjacent masses presents a great body of the Berkshire schist almost surrounded by the underlying Stockbridge limestone. The Berkshire schist sends out tongues, corresponding to synclines, into the Stockbridge limestone area. There are also reentering angles of limestone in the schist area, corresponding to anticlines. There are isolated schist areas which are more or less open synclines, and isolated limestone areas which are compressed anticlines protruding through the overlying schist, exposed by erosion. These relations recur between the Bellowspipe limestone (Sbp) and the Greylock phyllite (Sg), but the limestone area southwest of Cheshire appears to be a syncline.

Relation of geology to topography.—The physically and chemically more resistant schists form the more elevated portions and the steeper slopes, while the broad valleys and gentler undulations about the mountain generally correspond to limestone areas. The limestone and calcareous schist of the Bellowspipe limestone horizon constitute the benches of agricultural land high up on the sides of the mountain and the Notch ; and to the presence of this rock also, together with a northerly pitch, is due the deep incision in the central crest between Saddle Ball and Round rock. (See section Q and Pl. XIII and Fig. 74. The north to south part of the Hopper (Pl. XVII) is due to the trend and upturned edges of the calcareous belt, and possibly also to the minor anticline on the west side of this part of the Hopper. The deep east to west incisions on both sides of the mountain are the results of erosion crossing the strike, while the great spurs on the west side are portions of the original mass left by this erosion. The saddle between Greylock summit and Saddle Ball seen from the south (Pl. XV) is due to the central syncline of the mass (Sections I and K). The broader saddle seen from Mount Equinox on the north-northwest (Fig. 30, p. 136) is due to the great trough in the central syncline (Section Q). The center of this trough is the deepest part of the entire synclinorium.

In Appendix A, Stone hill, near Williamstown, and in Appendix B, New Ashford, are described in some detail. The former is accompanied by three transverse sections, S, T, U, which are crossed by the longitudinal section R′, from which it appears that a subordinate syncline passes through Stone hill and Deer hill, whence it probably continues southward through East and Potter mountains. The relation between Stone and Deer hills is analogous to that between Clarksburg mountain and Greylock.

MOUNT GREYLOCK EASTERN SIDE.

From a point on Hoosac mountain about 4 miles south of North Adams and 500 feet above Hoosic river, showing the mass from North Adams to Cheshire, 11 miles. In the northern half, the high bench of arable land (marked by 2 birds), Bellowspipe limestone, separated from the Hoosic valley by a steep area of the Berkshire schist. Above this bench the Ragged mountain mass Greylock schist, separated from the central ridge by the Notch; in the southern half the foothills of Berkshire schist separated from the central mass by areas of Bellowspipe limestone. From photographs

MOUNT GREYLOCK: ITS STRUCTURAL AND AREAL GEOLOGY.[1]

By T. Nelson Dale.

HISTORIC.

Mount Greylock, or Saddle mountain, has been an object of interest to geologists for seventy years. The most important work in structural and areal geology that has been done on the mountain is that of Prof. Chester Dewey (1817–1829), Prof. Ebenezer Emmons (1833–1855), Prof. Edward Hitchcock (1856–1861), and Prof. James D. Dana (1871–1887.) Prof. Emmons built upon and extended the investigations male by Prof. Dewey. In the writings of Profs. Dewey, Emmons, Hitchcock, and Dana,[2] the general boundaries between the limestone of the Hoosic and Green river valleys, and the schists of Greylock and Deer hill, and the quartzite of Stone hill are given. The synclinal structure of the Greylock mass, and

[1] A report to Prof. Raphael Pumpelly, in charge of the Archean Division, covering field work done under his direction in the summers of 1886, 1887, and part of 1888, by the writer, with the assistance during 1886 and part of 1887 of Mr. Wm. H. Hobbs.

[2] Amos Eaton: Index to the Geology of the Northern States. 1818. 2d ed. 1820.

Chester Dewey: Sketch of the mineralogy and geology of the vicinity of Williams College, Williamstown, Massachusetts (in a letter to the editor of the American Journal of Science, dated January 27, 1819, with a geologic map and section of the northwest part of Massachusetts). Am. Jour. Sci., ser. I, vol. 1, 1819, p. 337.

Chester Dewey: Geological section from the Taconick range in Williamstown to the city of Troy on the Hudson. Am. Jour. Sci., ser. I, vol. 2, 1820, p. 246.

Amos Eaton: Geological and agricultural survey of the district adjoining the Erie canal. 1824. (This includes a section from Hoosac mountain, Savoy, to the Hudson at Troy. It is reproduced in a paper by C. D. Walcott in the Tenth Annual Rept., U. S. Geol. Survey, 1888–89, p. 525.)

Chester Dewey: A sketch of the geology and mineralogy of the western part of Massachusetts and a small part of the adjoining states (with a geologic map of the county of Berkshire, Massachusetts, and of a small part of the adjoining states). Am. Jour. Sci., ser. I, vol. 8, part 2, 1824, p. 1.

Amos Eaton: A geological nomenclature for North America, founded upon surveys taken under the direction of the Hon. Stephen Van Rensselaer. Albany, 1828.

Chester Dewey: A general view of Berkshire county, forming part I of "A history of the county of the relation of the limestone to the schist were pointed out by Profs. Hall and Emmons, and confirmed by Profs. Hitchcock and Dana, and the complex character of that syncline was recently conjectured by Prof. Dana. Moreover, scattered through the writings referred to, are a number of important observations on portions of the mountain, to which reference will be made in proper place.

Of these writings, those of Profs. Emmons and Dana include the Taconic question, into the consideration of which the structural and areal geology of the Greylock mass partly enters. Notwithstanding the time that has elapsed since a geologic hammer was first applied to Mount Greylock, and notwithstanding the number and ability of the geologists who have lived and worked in its vicinity, little has been accomplished beyond

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Berkshire, Massachusetts, by gentlemen in the county, clergymen, and laymen." Pittsfield, 1829 (p. 190, "Geology," and "a geological map of the county of Berkshire, Massachusetts, and of a small part of the adjoining states, 1824").

Edward Hitchcock: Report on the geology, mineralogy, botany, and zoology of Massachusetts. First and second editions, Amherst, 1835.

Edward Hitchcock: Final report on the geology of Massachusetts. Amherst and Northampton, 1841.

Ebenezer Emmons: Taconic system, forming chap. VII of the Geology of New York, part II. Nat. Hist. of N. Y., part IV, Albany, 1842.

Ebenezer Emmons: The Taconic system, based on observations in New York, Massachusetts, Maine, Vermont, and Rhode Island, Albany, 1844.

Ebenezer Emmons: The Taconic system, forming chap. V. of vol. 1, of the Agriculture of New York. Nat. Hist. of N. Y., part V, Albany, 1846.

Ebenezer Emmons: American Geology, vol. 1, part II, Albany, 1855.

Edward Hitchcock: Report on the Geology of Vermont: descriptive, theoretical, economical, and scenographical. Proctorsville, Vermont, 1861, vol. 1, p. 255, vol. 2, p. 595, pl. XV, fig. 5.

James D. Dana: On the quartzite, limestone, and associated rocks of the vicinity of Great Barrington, Berkshire county, Massachusetts. Am. Jour. Sci., ser. III, vol. 6, 1873, p. 273.

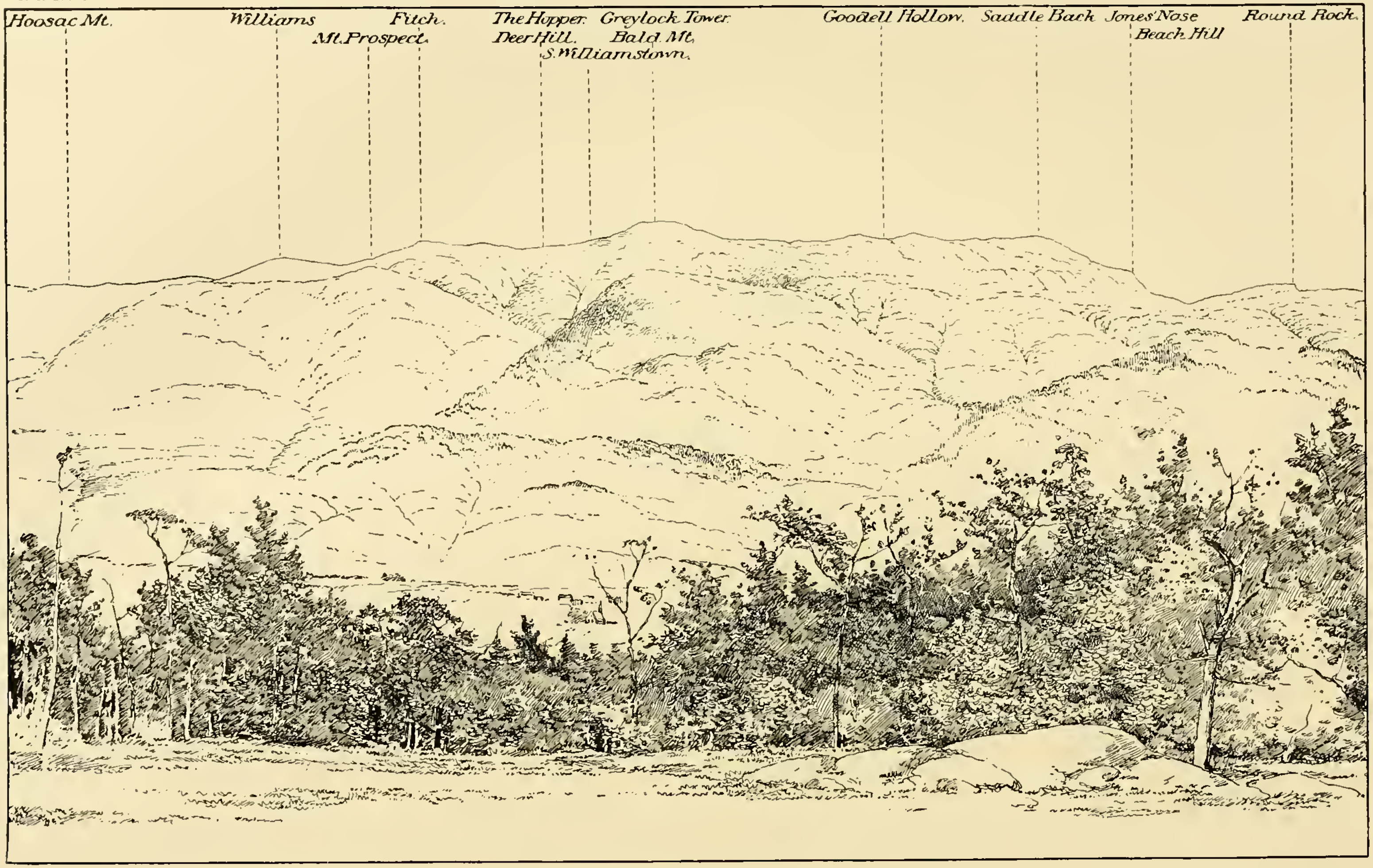
James D. Dana: An account of the discoveries in Vermont Geology of the Rev. Augustus Wing. Am. Jour. Sci., ser. III, vol. 13, 1877, p. 347.

James D. Dana: On the relation of the Geology of Vermont to that of Berkshire. Am. Jour. Sci. ser. III, vol. 14, 1877, pp. 41, 261-263.

James D. Dana: Note on the Age of the Green mountains. Am. Jour. Sci., ser. III, vol. 19, 1880, p. 191.

James D. Dana: On Taconic rocks and stratigraphy, with a geological map of the Taconic region. Part II. Am. Jour. Sci., ser. III, vol. 33, May, 1887, p. 405, 410.

James Hall: Section from Petersburg, New York, across Greylock to Adams, the basis of remarks of his at a meeting of the American Association of Geologists and Naturalists, between 1839-1844, both unpublished. See Am. Jour. Sci., ser. III, vol. 28, 1884, p. 311. "Prof. James Hall on the Hudson river, age of the Taconic slates."



MOUNT GREYLOCK, WESTERN SIDE.

Sketch of Mount Greylock, west side, taken from a point on the Taconic range west of South Williamstown, showing the two great western spurs, separated by the Hopper, with Deer hill in front of it; also the incision in the central crest south of Saddle Ball caused by tne erosion of the calcareous belt (Bellowspipe limestone).

what is above outlined, probably because of the wide reach of territory covered by the Taconic belt, and the overshadowing importance of the stratigraphic relations on either side of it, as well as the imperfection of the topographic maps hitherto published, and possibly because of the somewhat rugged character of portions of the mountain.

The raisons d'être of this report are: That Mount Greylock, in itself, offered one of the best fields for the study of the relations of the Taconic rocks to each other, and that sections across it, when extended eastward, northward, and southward, cut the underlying and older rocks where the latter were being studied in detail by the same division of the U. S. Geological Survey; that careful work here would aid in unraveling the geology farther west in eastern New York; that the geologic field work has been based upon a more correct topographic map; that the observations made have been very numerous (in all, 1,850), and have been carefully recorded on such a map; that the work has been done in the light of recent advances in orographic science, notably of the special investigations of Swiss and Norwegian geologists into the structure of metamorphic rocks; that a large collection of specimens has been gathered, illustrating principles of structure, from which large thin sections have been prepared for microscopic study; that the photographic camera has been freely used in the field as well as the study, and that the lithologic specimens gathered in the course of this structural work have been subjected to optical examination by a petrographer. Prof. Pumpelly has also brought his wide experience and critical judgment to bear upon the supervision of the entire work.

PHYSIOGRAPHIC.

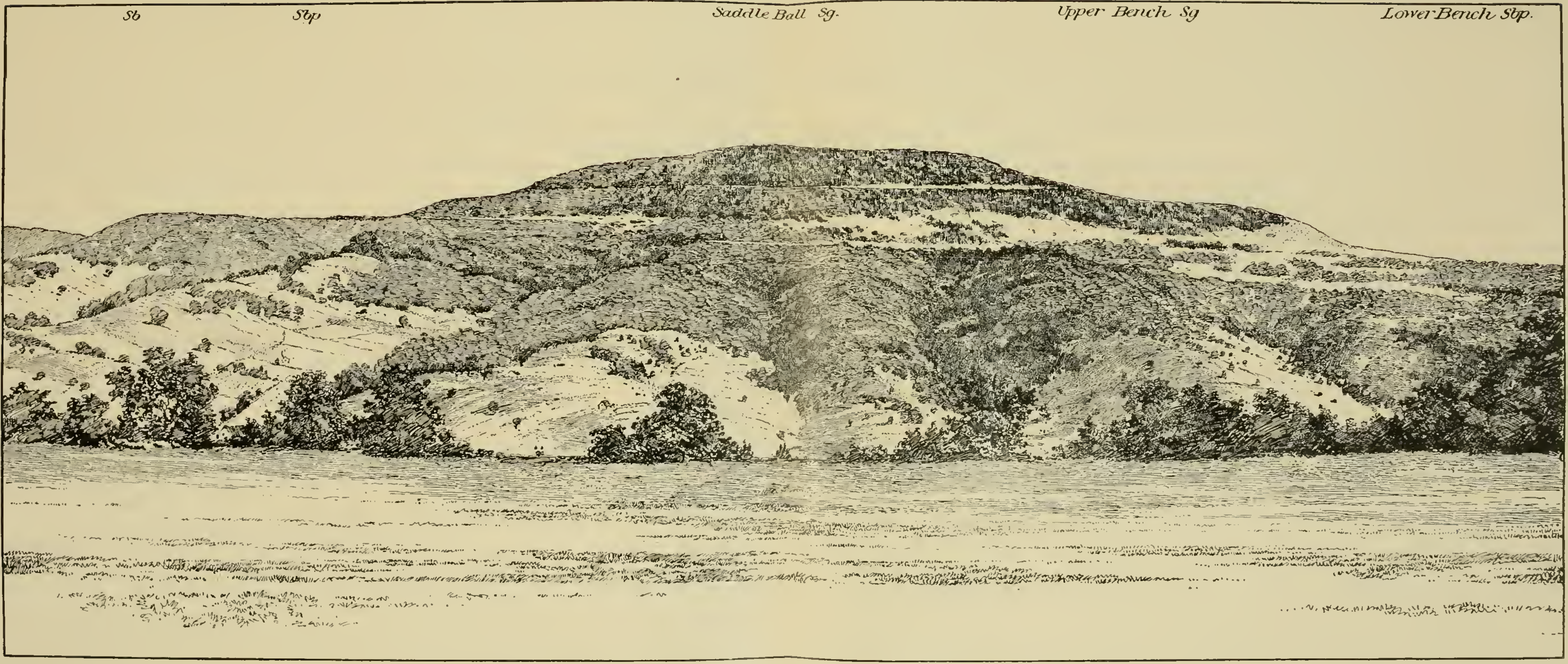
The northern third of the western portion of Massachusetts is marked by three main parallel mountain masses having the trend common to the Appalachian system. The most westerly is the Taconic range, the crest of which divides the states of New York and Massachusetts; the most easterly, situate about ten miles east of the New York line, is Hoosac mountain, and the central one is Mount Greylock. East mountain and Potter mountain together constitute a fourth but subordinate mass, connecting the Greylock mass with the Taconics farther south.

Mount Greylock with its spurs forms a topographic unit. It is separated on the north from Clarksburg or Bald mountain, a projection of the Green mountain range, by an east-west valley, through which the Hoosic river turns on its way to the Hudson; and from that point the Greylock mass rises 2,700 feet in a distance of 5 miles to an altitude of 3,505 feet above sea level, and thence descends more or less gradually for 11½ miles in a general south-southwestern direction, dying out in gentle undulations within about 2½ miles northeast of the town of Pittsfield. On the east it is separated from the Hoosac range by the alluvial and terraced valley of the Hoosic, while on the northwest it is divided from the Taconics by the broad and picturesque valley of Green river, which flows into the Hoosic at Williamstown. On the west and southwest it is separated from East and Potter mountains by the valleys and glens through which flow the headwaters of Green river on the north and of the Housatonic on the south.

The aspect of Mount Greylock from a point about 4 miles south of North Adams, on the flank of Hoosac mountain, embraces the eastern side of the mountain almost in its entire extent (Pl. XII), and shows a central mountain mass, of elongated but symmetrical form, with subordinate masses of similar shape and parallel trend, steep, rocky, wooded, and separated from the central ridge by areas of gently sloping cultivated land. This alternation of wood and meadow land, and the variety of form and color which it produces, are striking features in the landscape, and, as will be shown farther on, have much geologic significance.

The western aspect of Mount Greylock, from a point on the Taconic crest west of South Williamstown, forms a marked contrast to the eastern (Pl. XIII). Here the central crest is seen to descend rapidly about 2½ miles south of the summit, and then to rise a few hundred feet again. This incision in the crest is better shown in Fig. 74. Two powerful buttress-like spurs project from the central mass westwardly for over 2 miles. Their summits are but 900 feet lower than that of Greylock. The northerly spur, Mount Prospect, or Symonds peak, is separated from the southerly one, Bald mountain,[1] by a deep east-west cut, called the "Hopper." This cut branches out to the east into four deep ravines, which penetrate still

[1] This Bald mountain should not be confounded with Clarksburg mountain, which is sometimes called by that name and known also as Oak hill.



SOUTHERN SUMMIT OF MOUNT GREYLOCK.

The southern summit of the Greylock mass (Saddle Ball), west side, from the north foot of Sugarloaf mountain, New Ashford, showing the bench of arable land due to the calcareous schist (Bellowspipe limestone) and the still higher bench in the Greylock schist formation. From a photograph.

farther into the mountain, while on the west, across its mouth, lies Deer hill. (Compare Pls. XIII and XVII with the map, Pl I.) The portion of the western face south of these great spurs is best seen from the north end of East mountain or from the north end of Sugarloaf mountain in New Ashford. This shows (Pl. XIV), a few hundred feet below and parallel to the central crest, a very regular, horizontal bench over a mile in length, below which is a steep declivity followed by a far wider and longer bench of more or less open pasture land. (See also Fig. 74, p. 194.) Below this again the base of the mountain is deeply cut into by a series of east and west ravines parallel to the Hopper. The northern one of these is known as Goodell hollow.

The aspect of the Greylock mass on the south (Pl. XV) from the north end of the Lenox mountain range (known in Pittsfield as South mountain), which is about 15 miles south of the Greylock summit, shows the peculiar saddle shape of the higher portions of the mass which render the name of Saddle mountain so appropriate, and so familiar throughout southern Berkshire Greylock summit (3,505 feet) and Saddle Ball (3,300 feet), about 2 miles apart, form the two humps of the saddle, while the intervening portion of the crest with a southwesterly bend descending to the 2,900 feet contour forms its seat. This corresponds to internal stuctural features. This aspect also shows the subordinate ridges and spurs on either side of the mass as well as the benches on either side of its higher portions.

The aspect of Greylock from Clarksburg mountain on the north shows the central ridge with two lateral and lower ridges: that on the east—Ragged mountain—separated from Greylock proper by the Notch; that on the west, forming Mount Prospect and Bald mountain, separated from the center by a minor saddle, hence long ago also called Saddle mountain, which farther south passes into the north-south gorge continuous with the Hopper. From the Coast Survey station on Mount Equinox in Vermont, which is about 35 miles north northwest, and therefore at an acute angle to the strike of Greylock, the saddle form of the central crest appears much broader (Fig. 30). On the east of it the top of Ragged mountain is seen, and on the west several of the subordinate masses.[1] The structural significance of these

[1] Prof. Edward Hitchcock in his Final Report on the Geology of Massachusetts (1841, pp. 229-233) gave a very graphic description of Greylock.

topographic features will be noticed at the end. The area covered by the mountain, as thus defined, measures $16\frac{1}{2}$ miles by about $3\frac{1}{4}$; that is, about 53 square miles. If the short intervening range of East and Potter mount-

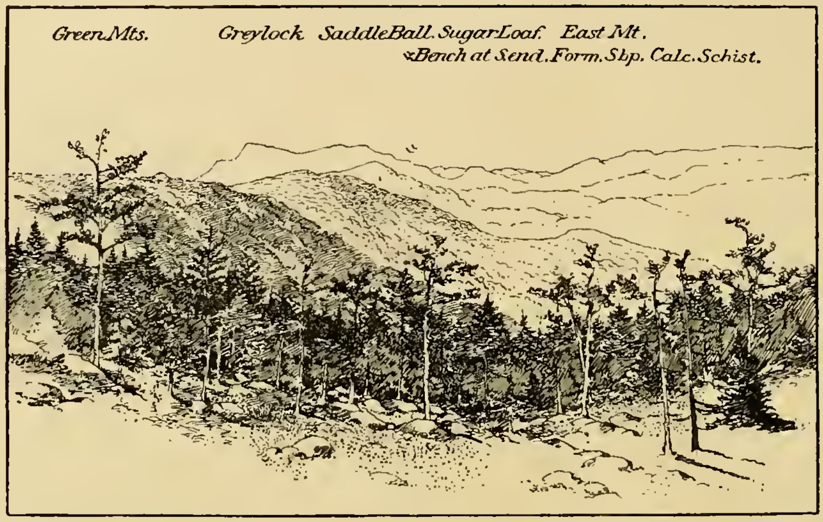


FIG. 30.—Sketch of Mount Greylock, "Saddle mountain," north-northwest side, from the U. S. Coast Survey station, on Mount Equinox, in Vermont, about 35 miles distant, showing the depression corresponding to the great trough in the central syncline, and the bench at the south end of the mass, due to the Bellowspipe limestone horizon (shown by 2 birds) Owing to the direction of the view the mountain appears much foreshortened.

ains be included (and structurally it belongs to the Greylock mass), the mountain area would measure about 85 square miles.

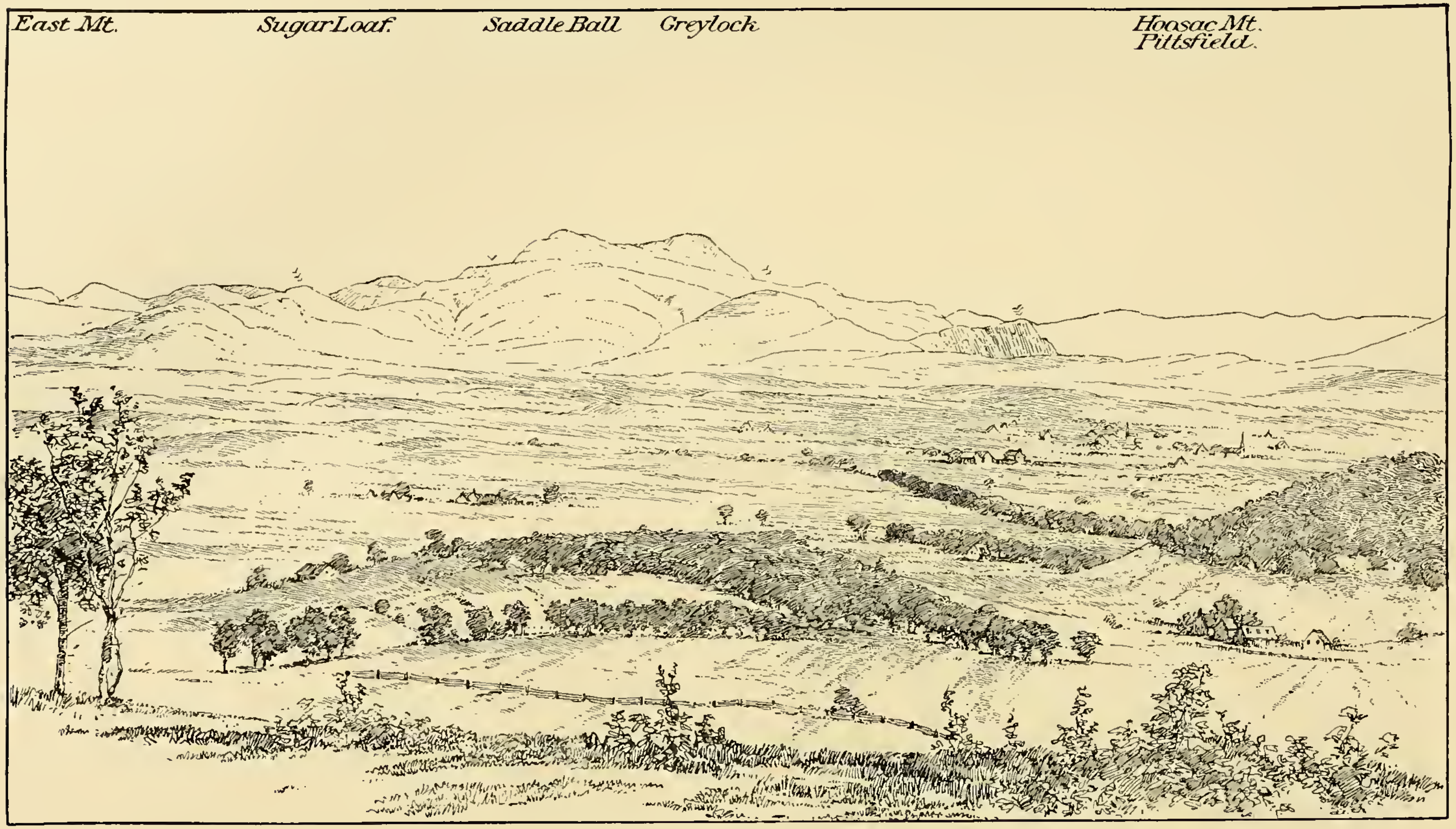
STRUCTURAL.

This entire area consists of a few kinds of metamorphic rocks: limestone, more or less crystalline and micaceous, quartzite, and schists—chloritic, feldspathic, pyritiferous, plumbaginous, calcareous. In the valleys, and along the lower and less inclined portions of the hills these rocks are covered with drift.

The key to the geologic structure of Mount Greylock is an understanding of the relations of cleavage and stratification and the relation of these to the pitch of the folds.[1]

There are large areas, sometimes half a mile square, where the only foliation presented by the outcrops is of secondary character and where no

[1] Although Professor Eaton, in his section of 1820, indicates cleavage on the Taconic range, its importance seems to have been overlooked by his successors in the study of this region.



SOUTHERN SIDE OF MOUNT GREYLOCK.

Sketch of Greylock or Saddle mountain, south side, from the north end of Lenox mountain, showing the saddle formed by the two summits, Greylock and Saddle Ball, due to the central syncline in the Greylock schist; also the broad benches on either side (marked by 1 and 2 birds) due to the Bellowspipe limestone formation; and the subordinate ridges and spurs (marked by 3 birds) due to minor folds in the Berkshire schist. The broad plain of the middle ground is underlaid by Stockbridge limestone.

trace of stratification can be detected. As the cleavage foliation in some places coincides with the stratification foliation both in strike and dip, in others agrees in strike while differing in angle of dip, and in still others differs from it in the direction of both strike and dip, and, furthermore, as the marks of stratification are not infrequently subject to purely local changes, the whole matter is attended with much difficulty. This is enhanced by the absence of all outcrops over considerable areas. Satisfactory results can be reached only by accumulating a great number of observations, rejecting those which appear in the least doubtful, and by closely studying the relations of the remainder. As a rule, the most reliable structural data on Greylock have been obtained from outcrops where two different beds were in visible contact, or from a series of related outcrops in all of which both cleavage and stratification foliations were equally manifest and discordant, or else from large surfaces of rock at right angles to the strike, where the general trend of the minor folds could be distinctly seen.[1]

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[1] The following list includes important recent works bearing on the subject of cleavage:

Theodor Kjerulf: Om Stratifikationens Spor (traces of stratification). Kristiania, September, 1877.

A. Heim: Mechanismus der Gebirgsbildung, im Anschluss an die geologische Monographie der Toedi-Windgällen-Gruppe. Basel, 1878.

A. Daubrée: Études synthétiques de géologie expérimentale. Paris, 1879.

H. Clifton Sorby: On the structure and origin of noncalcareous stratified rocks. Quarterly journal of the Geological Society of London, vol. 36, 1880, p. 72.

Ed. Jannettaz: Mémoire sur les clivages des roches (schistosité, longrain), et sur leur reproduction. Bulletin de la Société Géologique de France, 3rd ser., vol. 12, 1884, p. 211.

O. Fisher: On faulting, jointing, and cleavage. Geological Magazine, new series, decade 3, vol. 1, p. 205, 266, 396. London, 1884.

A. Harker: On slaty cleavage and allied rock-structures, with special reference to the mechanical theories of their origin. British Association Report. 1885 (1886), pp. 813–852.

T. G. Bonney: On the metamorphic rocks. Anniversary address. Quarterly Journal of the Geological Society of London, vol. 42, p. 35. London, 1886.

Hans Reusch: Geologische Beobachtungen in einem regional metamorphozirten Gebiet am Hardangerfjord in Norwegen. Neues Jahrbuch für Min., Geol. u. Pal., V Beilage-Band, Heft I, p. 53. Stuttgart, 1887.

Emm. de Margerie & Dr. Albert Heim: Die Dislocationen der Erdrinde; Versuch einer Definition und Bezeichnung. Zürich, 1888.

Henry M. Cadell: Experiments in mountain building. Transactions of the Royal Society of Edinburgh, vol. XXXV, part I, third series of experiments. Feb. 20, 1888. Abstract in Nature, vol. 37, p. 488. March 22, 1888.

Hans Reusch: Bømmeløn og Karmøen med omgivelser geologisk beskrevne. With an English summary of the contents. Kristiania, 1888.

T. Nelson Dale: On plicated cleavage foliation. Am. Jour. Sci., ser. III, vol. 43, 1892, p. 318.

Geo. F. Becker: Finite homogeneous strain, flow and rupture of rocks. Bull. Geol. Soc. Am., vol. 4, 1893, pp. 13–90.

TYPES OF STRUCTURE.

In order to present this matter more clearly, a few typical localities will here be described in some detail.

CASE I.

On Quarry hill, close to the village of New Ashford,[1] there are several minor folds in the limestone and the overlying schist, where the two rocks may be seen in contact. Fig. 31 represents the structure at one of these points of contact, locality 602 on sketch map, Fig. 78.

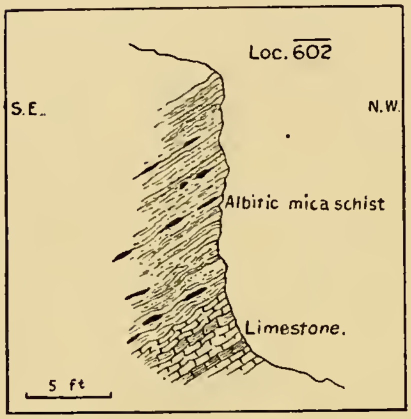


FIG. 31.—Diagrammatic sketch showing albitic schist in conformable contact with underlying crystalline limestone, the foliations of both rocks dipping 30° SE. Locality 602, Quarry hill, New Ashford.

The banding in the limestone, the plane of contact, the small quartz laminæ, and the general, slightly undulating foliation in the overlying coarse, feldspathic schist, all dip in the same direction at an angle of about 30°.[2] There is little room for doubt that the foliation in the schist here, whatever its cause, is parallel with the stratification, and that both rocks are conformable. This is the normal structure.

T. Nelson Dale: The Rensselaer Grit Plateau in New York. Thirteenth Annual Report, U. S. Geol. Survey, 1893, pp. 291–340.

Of the older well-known works on this subject the following are the most important:

A. Sedgwick: On the structure of large mineral masses. Trans. Geol. Soc. of London, 2nd ser. vol. 3, 1835, pp. 68, 461.

Charles Darwin: Geological observations on South America, being part III of the geology of the voyage of the *Beagle*. London, 1846. Chap. VI. Plutonic and metamorphic rocks; cleavage and foliation.

Daniel Sharpe: On slaty cleavage. Quarterly Journal, Geol. Soc. London, vol. 3, 1847, p. 74.

Henry Clifton Sorby: On the origin of slaty cleavage. Edinb. New Philosophical Journal, vol. 53, 1853, p. 137.

John Phillips: Report on cleavage and foliation in rocks, and on the theoretical explanations of these phenomena. Report of British Association for the Advancement of Science, Part I, 1856, p. 369.

Henry Clifton Sorby: On slaty cleavage as exhibited in the Devonian limestone of Devonshire. Philosophical Magazine, ser. IV, vol. 12, London, 1856, p. 127.

John Tyndall: On the cleavage of slate rocks. Philosophical Magazine, ser. IV, vol. 12, London, 1856, p. 129.

Samuel Haughton: On slaty cleavage and the distortion of fossils. Phil. Mag., ser. IV, vol. 12, London, 1856, p. 409.

[1] See Appendix B, Figs. 77, 78.

[2] All compass readings in this report are corrected for variation.

CASE II.

About 150 feet northeast of locality 602 there are two very small folds in the limestone, passing into a very low southwesterly dip on the west. (See Figs. 32 and 78.) In the overlying plumbaginous schist there are corresponding undulations, but these are compounded of more minute ones and crossed by cleavage planes. Where the plications dip 50° southwest the cleavage planes dip 40° to 50° east. Where the former dip 15° to 20° southwest the latter dip 35° east, and, again, where the former are more nearly horizontal the latter are vertical. Fig. 33, taken from the upper portion of the section (Fig. 32), shows the relations first described. Fig. 34, taken from a slightly enlarged photograph of a large section of a specimen from the same portion of the ledge, shows more distinctly what is but slightly apparent in Fig. 33, namely, that the cleavage planes arise in a faulting along the shanks of the plications. In many cases the faulting is only incipient. In a specimen from the central part of the ledge where the cleavage planes are vertical they are simple joint-like fractures across the stratification foliation of the schist, but along one of these faulting has occurred, and the stratification foliation is bent about into the direction of the cleavage.

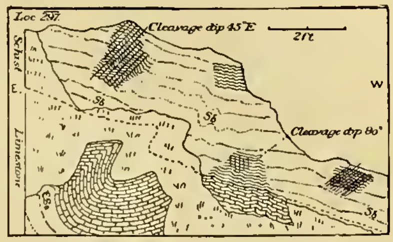


FIG. 32.—Diagrammatic sketch of the north side of a ledge at locality 297, on Quarry hill, New Ashford, showing plumbaginous schist in conformable contact with underlying crystalline limestone, and a cleavage foliation crossing the stratification foliation of the schist at various angles.

FIG. 33.—Specimen in inverted position, facing south, from the upper part of the rock figured in Fig. 32. locality 297, Quarry hill, New Ashford. Plumbaginous schist with a stratification foliation dipping southwest about 50°, crossed by a coarse cleavage foliation dipping 40°-50° E. From a photograph.

We have here, then, a cleavage which is in part a microscopic jointing, in part what Heim has called "Ausweichungsclivage[1]" (slip cleavage),

[1] See Heim, op. cit., vol. II, p. 51, Gesetz 7, and Atlas, Pl. XIV, Figs. 17, 18; Pl. XV, Figs. 7, 8, 9, 11, 14.

resulting in a coarse foliation crossing the stratification foliation at angles varying from 45° to 90°, and abutting against the limestone which underlies the schist in conformable contact.

FIG. 34.—Thin section of a specimen from the upper part of the rock figured in Fig. 32, locality 297, Quarry hill, New Ashford, enlarged almost 2 diameters, showing cleavage planes arising in slight faults along the sides of the plications. The fractures which occurred in the preparation of the slide are mainly in the direction of the stratification foliation, which here dominates.

CASE III.

At the south end of Sugarloaf mountain, one of the subordinate folds of the Greylock mass, a small isolated mass of feldspathic schist overlies the crystalline limestone. (See map, Pl. I, locality 324 and Fig. 35.) Here limestone and schist are seen in contact, both distinctly plicated, and

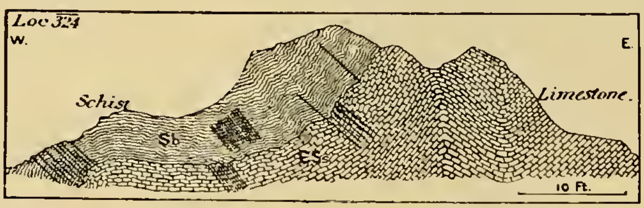


FIG. 35.—Diagrammatic sketch of the south side of a ledge at locality 324, south foot of Sugarloaf mountain, New Ashford, showing albitic schist in conformable contact with underlying crystalline limestone, and a coarse and fine cleavage foliation crossing the stratification foliation of both rocks.

dipping in a general westerly direction, but really forming part of a minor fold. Where the stratification foliation dips 60° west it is crossed by cleavage planes dipping 35° east, which in places traverse both rocks. The limestone a few feet away from the schist appears in thick beds. Both schist and limestone are traversed here and there by coarse or fine cleavage.

The presence of both cleavage and stratification in limestone is also seen in a small mass a little north of this locality (Fig. 36), probably

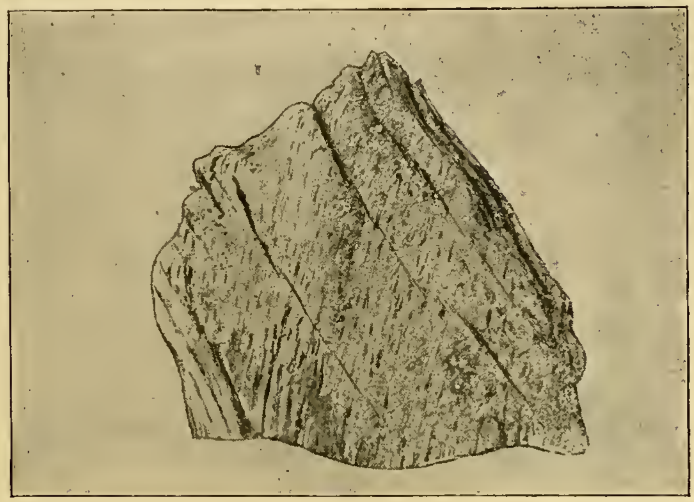


FIG. 36.—Block of limestone 3 feet high on the southwest foot of Sugarloaf mountain, New Ashford, showing a coarse stratification foliation dipping to the right, crossed by a fine cleavage foliation dipping to the left. From a photograph.

detached from some part of the foot of Sugarloaf mountain, and still more strikingly and on a large scale on the east side of the same mountain, (locality 590, Fig. 37). The cleavage foliation dips here about 20° east,

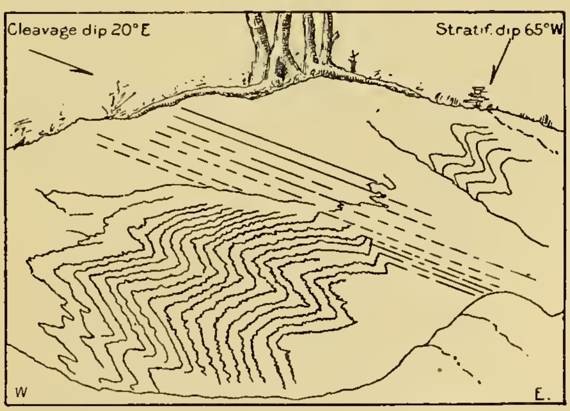


FIG. 37.—Sketch of the south side of a limestone ledge at locality 590, on the east side of Sugarloaf mountain, showing a coarsely plicated stratification foliation dipping about 65° west, crossed by a cleavage foliation dipping about 20° east. Area, 25×15 feet.

and the stratification about 65° west. In some of the neighboring ledges only the easterly dipping foliation is visible.

On the east side of East mountain, near the old marble quarries and sawmill (locality 756), there is a ledge of limestone with a thin lamination

FIG. 38.—Specimen from the weathered end of a limestone ledge at locality 756, east side of East mountain, showing a plicated stratification foliation dipping to the right and a cleavage foliation to the left. Photographed in inverted position.

dipping 25° to 40° east. On a closer examination the weathered end of the ledge shows that this is crossed by a plicated foliation dipping 30°

FIG. 39.—Polished surface of limestone specimen, Fig. 38, in its natural position, facing south, showing stratification dipping west and cleavage east. From a photograph.

to 40° west. The presence of a little quartz in some of the stratification planes makes the plications project on the weathered surface. (See Fig. 38).

On a polished surface they can easily be traced. (See Fig. 39.) On the north side of the ridge, south of the Hopper, (locality 899) the stratification foliation is indicated by white calcite meandering through the gray limestone. At a small cave about two-thirds of a mile northeast of the Lanesboro Iron Company's ore bed (locality 998) the relation of cleavage to stratification in limestone is also clearly seen. That the plane foliation is cleavage foliation is rendered highly probable from the usual character and origin of such foliation[1]. There may be cases, however, where it would be difficult to decide whether the plications in limestone are due to "false bedding" or to original stratification.

From all this it appears that cleavage phenomena in the Greylock area affect both schist and limestone.

CASE IV.

In some loose pieces of limestone found on Quarry hill, New Ashford,

FIG. 40.—Loose piece of limestone from Quarry hill, New Ashford, showing on the weathered surface laminæ of micaceous matter in both cleavage and stratification planes. The nearly horizontal laminæ represent the stratification foliation. From a photograph.

both cleavage and stratification foliation are indicated by laminæ of mica-

[1] Cleavage foliation may be subsequently bent, but this rarely occurs. See Ch. Darwin, loc. cit., also J. B. Jukes: Student's Manual of Geology, edited by Archibald Geikie, 3d ed., Edinburg, 1872, p. 224, 225. Dr. H. Reusch in his Geology of the Islands of Bömmelö and Karmö, etc., already cited, describes on p. 196, Fig. 2, and p. 408, an interesting specimen from Föien, an islet at the mouth of the Hardangerfjord in Norway. The specimen figured shows both the original stratification foliation (plicated) and the ensuing cleavage foliation (slip cleavage), and also the secondary plication of both of these foliations, all on a small scale. One or two Greylock specimens show a slight flexure of the cleavage foliation. Plicated cleavage in the Taconic range at West Rutland, Vt., is described in the author's report on the Rensselaer Grit Plateau in the Thirteenth Annual Report of the Director of the U. S. Geological Survey, pp. 291–340. See also A. Baltzer, op. cit. (p. 152), pl. XIII, fig. 11.

ceous matter which project on the weathered surface. (See Fig. 40). These specimens clearly indicate infiltration and metamorphism subsequent to cleavage.

CASE V.

The stratification foliation and the cleavage foliation are both sometimes minute in the schist and equally dominant. Fig. 41 represents such a specimen from Bald mountain on the west side of Greylock.

FIG. 41.—Specimen of schist from locality 95 on Bald mountain, west side of Greylock, not in natural position, showing both stratification and cleavage foliations somewhat minute and equally dominant. Each pair of opposite sides of the block is parallel to one of the foliations, cleavage dips to the left. From a photograph.

FIG. 42.—Specimen of schist from locality 621, north end of Mount Prospect, in natural position, facing south, showing only cleavage foliation dipping 50° east.

Fig. 42 represents a specimen from Mount Prospect in which only cleavage planes dipping 50° east are visible to the naked eye. Under a magnifying glass the stratification foliation barely appears in minute crinkles crossing the cleavage planes, but the cleavage foliation dominates. These crinkles come out more clearly in an enlarged section (Fig. 43) and indicate a westerly dip, which is confirmed by observations on some of the neighboring ledges, where the stratification foliation, marked by small plicated quartz laminæ visible to the unaided eye, dips at a high angle west. Similarly some of the schists on Bald mountain, near where specimen 95*d* (Fig. 41) was obtained, show nothing but cleavage planes, and even under the

Fig. 43.—Thin section of part of specimen, Fig. 42, enlarged 2½ diameters, showing a minute, plicated stratification foliation crossing a fine cleavage foliation. Fractures in preparing slide took place along the cleavage which here dominates.

microscope barely reveal the other foliation. The structural character and relations of these foliations appear in Figs. 44 and 45, which show how the crinkling, and sometimes the exceedingly minute faulting of the small

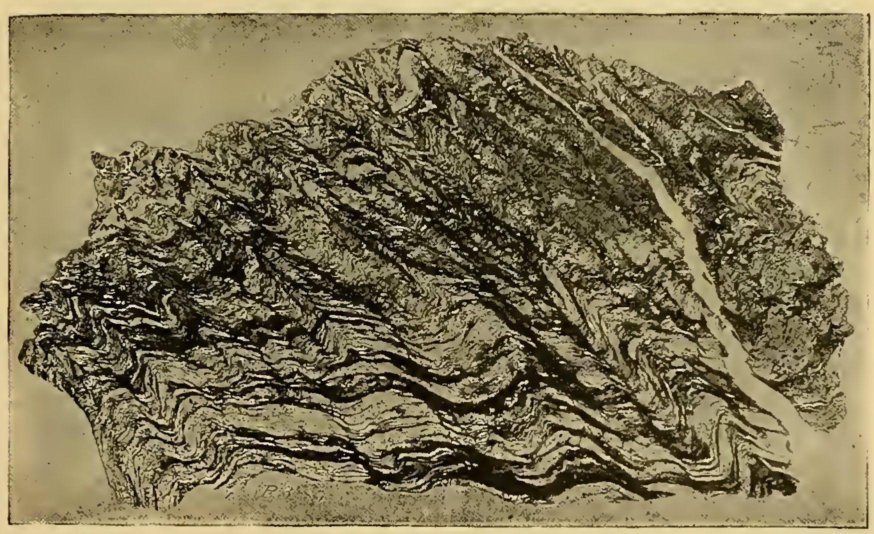


Fig. 44.—Thin section of a specimen of schist from near the top of Mount Greylock, enlarged 2½ diameters, showing the development of slip cleavage from the crinkling of the laminæ of quartz and folia of mica and chlorite. The fracture on the right follows mainly the direction of the cleavage. From a photograph.

laminæ of quartz and folia of muscovite and chlorite of the stratification foliation produce cleavage planes. The schists of the Taconic range show these foliations on a still more minute scale, These facts indicate that stratification foliation and cleavage foliation may be equally or unequally dominant or microscopic.

FIG. 45.—Microscopic drawing of about $\frac{1}{4}$ inch square of a thin section of a specimen of schist from locality 741, on East mountain, enlargement 39 diameters. The light portions are mainly quartz, the dark mainly sericite and chlorite. The central plication shows the development of cleavage from a slight crinkling to a complete fault. Another cleavage plane, about $\frac{3}{4}$ of a millimeter to the right, contains some ferruginous matter.

CASE VI.

Frequently small lenticular masses or laminæ of quartz of irregular thickness occur in the schists. Their form and direction are sometimes so irregular as to give no information as to structure, but they sometimes show a general parallelism either to the cleavage foliation or to the stratification foliation or to both. Fig. 46 represents a specimen from locality 550, about 1,500 feet south and 500 feet below the Greylock tower.

The specimen consists of two parts, a mass of schist about 3 inches thick, capped by a quartz lamina about a half-inch thick, which undulates conformably to the general stratification foliation of the schist. The stratification foliation dips west at a very low angle, while the cleavage foliation dips 60° east. Within a space of 2 inches the schistose part of the specimen shows as many as twenty cleavage planes crossing the stratification foliation, besides quite a number of incipient cleavage planes. Within the same space the quartz is traversed by nine to ten fissures which, although not always continuous with the cleavage planes of the schist, yet preserve their general direction. All the minute undulations in the schist are generalized in the quartz. This is also shown in a specimen from the west side of Deer hill. Here there are two undulating quartz laminæ generally parallel to each other. While the thicker one makes an S-shaped curve, the

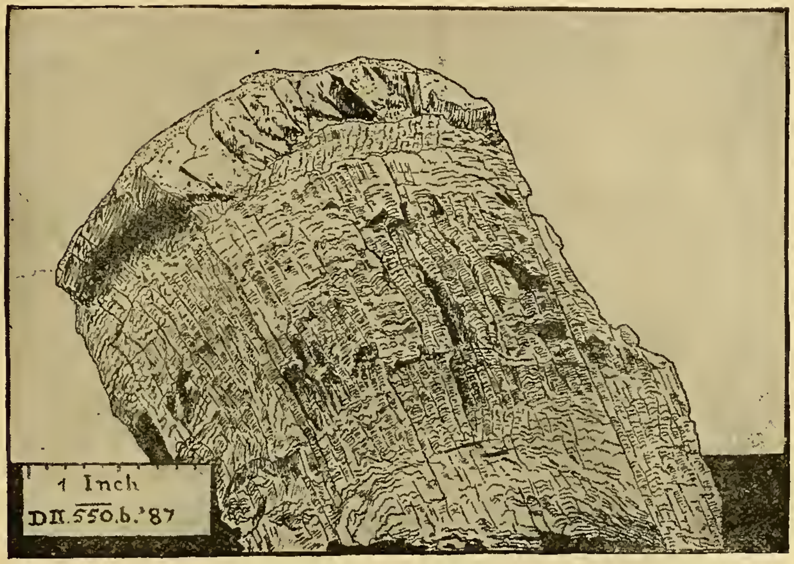


FIG. 46.—Specimen of schist from locality 550, about $\frac{1}{4}$ mile south of Greylock summit, in natural position, showing in upper part a quartz lamina about $\frac{1}{2}$ inch thick, conforming to the general course of the minute plications, which dips west at a low angle while the cleavage dips 60° east. From a photograph.

thinner one is plicated in the same distance as many as nine or ten times. As geologists have observed, such coarse quartz laminæ in schist often run parallel to the cleavage foliation. In order to arrive at their true stratigraphic significance, not only should their general dip over a large surface be noted, but allowance should be made for their passing into the cleavage foliation for any considerable distance, especially when the dip of that foliation forms a considerable angle with that of the stratification foliation. Fig. 47 illustrates the relation of quartz laminæ to the cleavage foliation. The cleavage here dips about 50°; the laminæ in a few places, and for short distances, dip at the same angle, but vary from 30° to 90°, while their general dip ranges from 40° to 80°; and the stratification dip lies between those extremes, being probably higher than the cleavage dip. If it could be shown that such laminæ are infiltrations in fissures following alternately either of the foliations, those portions of the laminæ which do not follow the cleavage foliation would alone afford reliable indications, but if their occasional parallelism to the cleavage foliation represents parts of the course of the stratification their general dip should be taken.

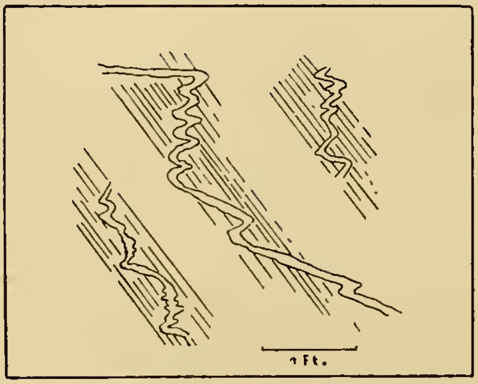


Fig. 47.—Quartz laminæ in relation to cleavage in schist, from locality 126, south of Deer hill.

At locality 207, near the junction of Gulf brook and Ashford brook, there is a large ledge of schist which shows very finely the relations of these plicated thick quartz bands to both the stratification and cleavage foliations. Fig. 48 represents the south side of the ledge. The minute plications (stratification) of the schist and of the thin quartz laminæ are generalized

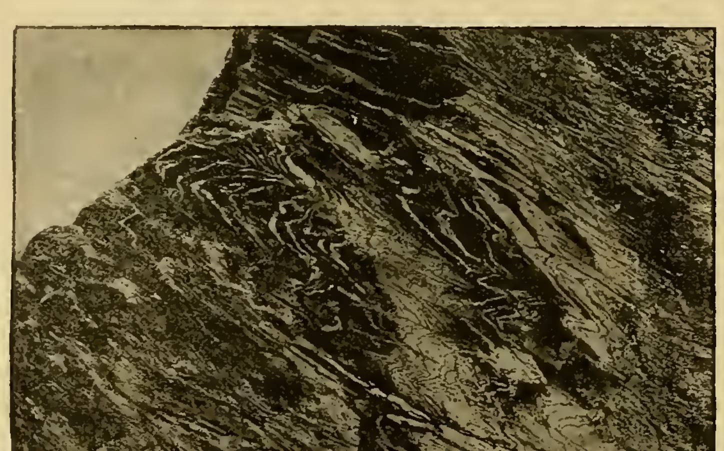


Fig. 48.—South side of schist ledge, locality 207, junction of Gulf and Ashford brooks, showing the relation of the general dip of the quartz laminæ to the minute plications. This dip is 60° to 70°. The cleavage foliation, which includes a thick quartz lamina below, dips 35°. Area 14x10 feet. From a photograph.

in the broader undulations of the thick quartz laminæ which have an average dip of 60° to 70°. There is also a well-marked cleavage foliation dipping 35° in about the same direction. The cleavage planes do not traverse the thick quartz laminæ. Microscopic sections across both schist and quartz show the parallelism of the minute plications of the schist with the adjoining quartz, and the cleavage planes of the former terminating at the quartz. There is at least one thick quartz lamina in and parallel to the cleavage foliation. Through a large part of the more micaceous portion of the ledge no stratification foliation is visible to the naked eye or under the magnifying glass; and even under the microscope the mass shows only a wedge-shaped structure, all the minute folia lying with their axial planes either parallel to the cleavage foliation or at a very acute angle to it.

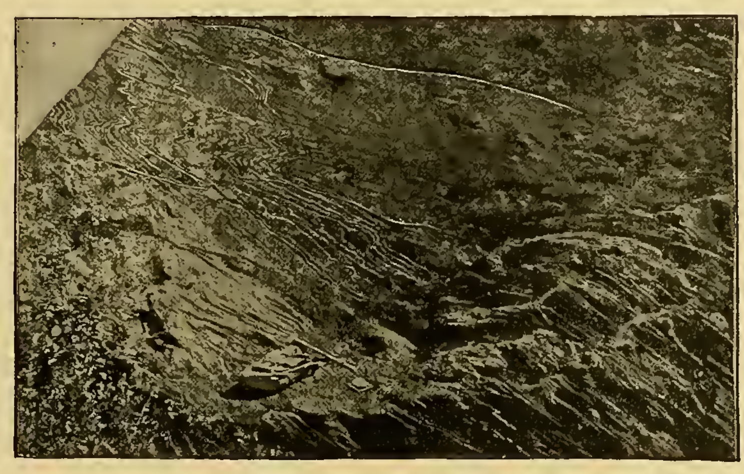


FIG. 49.—Southwest and part of south side of schist ledge (Fig. 48), showing the relation of the two foliations. Area 15×8 ft. From a photograph.

Fig. 49 represents the southwest side of the same ledge, together with a portion of its southern side, and also shows the relations of the two foliations. The behavior of the cleavage and stratification foliations, when in proximity to a thick quartz lamina, is beautifully shown in Fig. 50, which represents a section from a specimen from locality 184, in Goodell hollow. The general parallelism of the coarse quartz lamina to the minute plications in the schist on either side of it and the cleavage planes arrested by the quartz will be observed. The longitudinal cracks in the quartz are possibly due to strain, as are also the transverse cracks in the quartz lamina in Fig. 40.

These facts indicate that the dip of the stratification foliation may be shown by the general dip of the thick quartz laminæ when such laminæ can be distinguished from cleavage foliation quartz laminæ. Locality 207 furthermore shows that stratification foliation may be so completely obliterated that cleavage foliation alone is determinable.

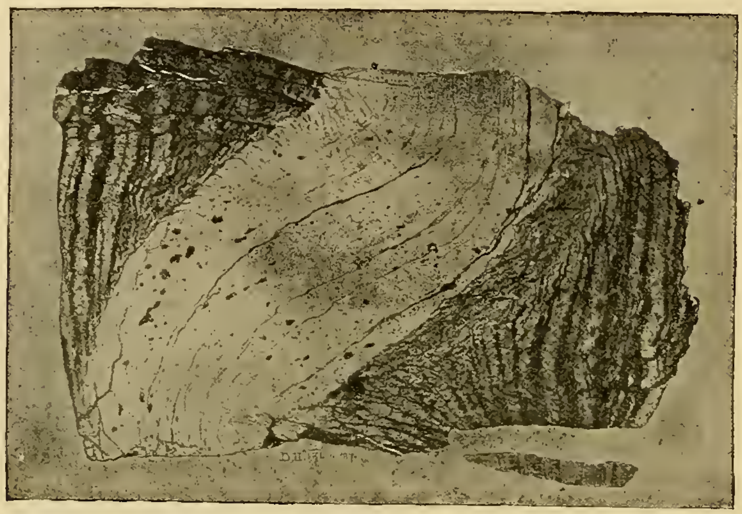


FIG. 50.—Thin section of sericite-chlorite-schist traversed by a coarsely plicated quartz lamina, from locality 184, Goodell hollow, enlarged 2 diameters, showing the relation of the cleavage to the quartz. In preparing the slide fractures have occurred along cleavage planes. From a photograph.

CASE VII.

On the southwest side of Bald mountain, locality 242, the schist is traversed by two sets of foliations with different strikes The stratification foliation, distinguished by its plications, and in part by the continuity of the mineral constituents of the laminæ, strikes north 40° to 50° east, and dips 60° southeast. The cleavage foliation strikes north, and dips 35° to 40° east. The correctness of this observation is corroborated by one at locality 95, on the northern face of Bald mountain, about 4,000 feet nearly in the direction of the stratification strike as thus determined. There the stratification foliation is indicated by great sheets of quartz striking north 45° east, and dipping about 75° southeast, corresponding to the minute plications in the surrounding schist, which are crossed by a cleavage foliation striking north 3° to 5° east, and dipping 55° east. The probable correctness of both these observations is still further increased by the trend of the central ridge of Greylock, which, southeast of those localities, is also northeast. A large ledge of schist at Readsboro, in Vermont, in the Green mountain range (Fig. 51), shows on a large scale the two sets of foliations and quartz laminæ, with different strikes and dips, and will serve to illustrate what is not uncommon on Greylock in similar rocks.

The parallelism between the strike of the cleavage and the strike of the axis of the great folds has long been recognized in geology. When, therefore, the axis of the fold lies horizontally the strike of the sides of the fold will conform to the strike of the cleavage; but when the axis of the fold is inclined, i. e., when the fold pitches, the strike of the sides of the fold will not conform to that of the cleavage. This, Prof. Pumpelly suggests, is the most probable explanation of these differences between the strikes of the stratification and cleavage. The conformity which Heim finds in the Alps between the strikes of the two foliations does not hold here.[1]

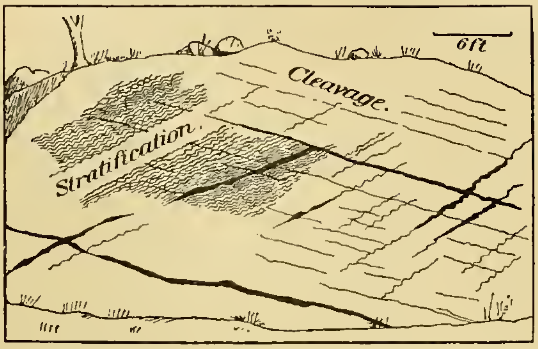


FIG. 51.—Sketch of west side of schist ledge in Readsboro village, Vt., showing stratification striking N. 20° E., and dipping 25° west, crossed by cleavage striking N. 15° W. and dipping 55° east, with quartz laminæ in both foliations. As the face of ledge is not parallel with the strike of either foliation the apparent angles of dip are not the true ones.

CASE VIII.

In Goodell hollow, locality 175, southwest of Bald mountain, there is a schist with three sets of planes or foliations, set *a* striking north 5° east, and dipping 35° to 45° east; set *b* striking north 20° east, and dipping 40° east; set *c* striking north 80° east, and dipping 70° north. An enlarged thin section (Fig. 52) shows that the minute plications follow the direction of set *b*, while set *a* is formed by a slip cleavage more or less pronounced, and set *c* by the infiltration of dark mineral matter in planes, possibly fractures, traversing the other two sets without altering their structure. This interpretation of this locality is also confirmed by the strikes and dips observed in its vicinity. At locality 132, near the west end and on the

[1] See his law 13, op. cit., vol. 2, p. 68.

south side of the Bald mountain spur, there is a small ledge in which the stratification foliation dips 35° west, the cleavage foliation 25° to 30° east, and a secondary cleavage horizontally or very low west. Some vertical joints strike north to south through all these planes.

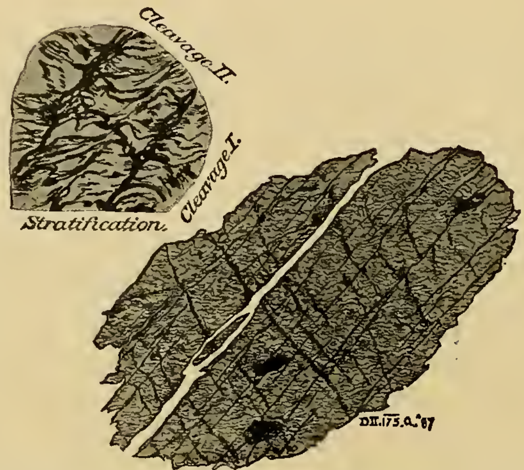


Fig. 52.—Thin section of sericite-chlorite-schist from locality 175, Goodell hollow, the larger figure enlarged nearly 2 diameters and the smaller about 10 diameters, showing two cleavage foliations crossing the stratification. In preparing the slide a fracture has occurred along Cleavage I. From photographs.

Secondary cleavage foliation occurs here and there in the Greylock area.[1]

CASE IX.

Fig. 53 represents an enlarged section of plicated schist from locality 550, about 1,500 feet south of the top of Greylock. The area in the larger and upper fragment measures 1½ by ½ inches. The specimen from which the section was made showed, in its original position in the ledge, a stratification foliation about horizontal or dipping west at very low angle, crossed by a cleavage foliation dipping 60° east. From the direction taken by the breaks, which occurred in the preparation of the slide, it seems probable that in some portions of the rock here the cleavage foliation dominates. Fig. 46 represents a hand specimen from the same ledge in its natural posi-

[1] Two sets of cleavage planes are noticed in the slate on Welden's island, Lake Champlain. Geol. Report Vermont, vol. 1, p. 314. A. Baltzer, in the Beiträge zur geologischen Karte der Schweiz (20te Lieferung, Bern, 1880. Atlas, pl. III, fig. 8, and XIII, figs. 14, 16) figures two cleavage foliations traversing the same rock. Archibald Geikie, in his report on the recent work of the Geological Survey in the northwest highlands of Scotland, describes a double foliation in eruptive gneiss. Quart. Jour. Geol. Soc., London, vol. 44, Aug. 1888, p. 398–400.

tion. The same stratification foliation and cleavage foliation dips recur at locality 549, some 2,500 feet south-southeast, and at locality 539 (see Fig. 54) about 1,000 feet west, and again at the top of Greylock, and may thus be said to characterize the entire eastern portion of the summit of the mountain. If, therefore, the larger microscopic specimen in Fig. 53, which only measures 1½ by ½ inches, be properly oriented it will correctly represent the structure of an area measuring about two-thirds of a square mile, and probably the entire east side of the highest syncline of the Greylock mass. (See Sections G, H, I, Pl. XX.)

FIG. 53.—Thin section of sericite-chlorite-schist from locality 550, about one-quarter mile south of Greylock summit, enlarged 2½ diameters, showing a coarse slip cleavage crossing a very minutely plicated stratification. In preparing the slide fractures occurred mainly in the direction of the cleavage, here the direction of least resistance. From a photograph.

The microscopic structure thus often epitomizes the general structure on one side of a fold. This fact agrees with the drift of what Mr. Heim implies in regard to the structure of the Toedi-Windgaellen-Gruppe namely, that physical causes have transformed great masses by transforming the minute particles which constitute them.[1] This generalization must not be

[1] Op. cit., vol. II, p. 99.

carried too far, however, for local changes may occur for a brief space in the direction of the plications and of the cleavage foliation, owing to the presence of quartz nodules; or there may also be minor undulations on the side of a great fold.

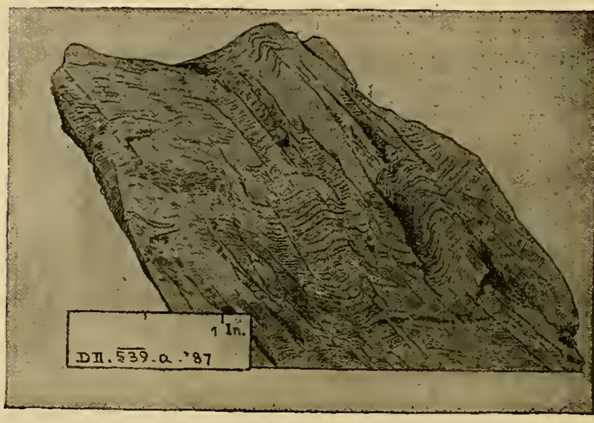


FIG. 54.—Specimen of schist from locality 539, about one-quarter mile southwest of Greylock summit, in its natural position, facing south. Stratification nearly horizontal; cleavage dip 50°-55° east. From a photograph.

CASE X.

The above cases are sufficient to illustrate the structural significance of stratification and cleavage and the distinction between them in the region under investigation. With the aid of these a fault was detected which would otherwise have escaped notice. Near the west end of the Bald mountain spur there is a somewhat lenticular area of limestone trending north and south, and in contact on both sides with schist. On the west side the contact phenomena are as indicated in Fig. 55. The limestone overlying the schist dips from 45°–60° east, the contact plane between both 55° east; the schist cleavage dips 25°–55° east, but the plications in the schist dip *west* at a somewhat higher angle. The normal position of this limestone is under the schist; here it is above in consequence of a fault. At this point the stratification foliation in the schist is very much plicated, and the cleavage faulting divides up the rock into lens

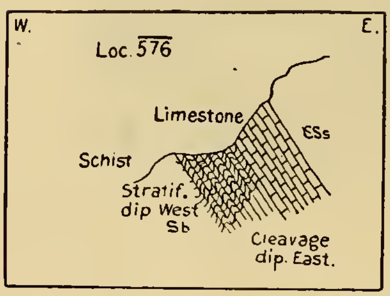


FIG. 55.—Diagram showing the relations of the Berkshire schist and Stockbridge limestone at locality 576, on the Bald Mountain spur, looking north. The cleavage of the schist conforms to the stratification of the limestone, but the stratifications are unconformable.

or wedge-shaped masses. This is the typical slip cleavage. The minute structure at the contact, as seen in a microscopic section, corresponds to that represented in the diagram, Fig. 55. The inference from such facts is that while conformable contacts are all-important in determining stratigraphic relations in a metamorphic region they may be entirely misleading unless it can be shown that the foliations which conform to the plane of junction between both rocks are indeed stratification foliation.[1]

CORRELATION OF CLEAVAGE AND STRATIFICATION.

The facts adduced naturally raise the question as to the general correlation of cleavage and stratification. The relations of the strikes of the two foliations have already been explained under Case VII. As to the dip

FIG. 56.—Thin section of schist from locality 115, on the Bald Mountain spur, enlarged 1½ diameters, showing the parallelism between the cleavage planes and the axial planes of the plications. From a photograph.

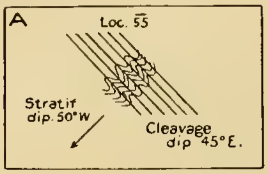
of the two foliations: The range of the difference in angle of dip between cleavage foliation and stratification foliation in sixty-three observations was found to be from 10° to 120°;[2] the average difference 62°, 30′. The absolute dip of cleavage in ninety-six observations, in which the dip of stratification foliation was also observed, ranged from 10° to 90°, averaging about 45°; leaving out eleven extreme cases the range was from 25° to 75°, and the average 44°.[3] The direction of the dip of the primary cleavage in one hundred and nineteen localities, in which that of the stratification was also determined, was distributed as follows: ninety-two localities east or northeast, twelve west, four vertical, one south. The southerly dip occurs at the

[1] Compare J. D. Dana, Taconic rocks and stratigraphy. Am. Jour. Sci., Ser. III, vol. 33, May, 1887, p. 398, in which the possibility of such cases as this is overlooked.

[2] When the difference is over 90° the direction of the two dips is opposite.

[3] Where cleavage is horizontal and stratification nearly or quite vertical, as is sometimes the case in the Berkshire county schist, there have probably been two uplifts.

north foot of Mount Prospect (Saddle mountain) where there is a well marked southerly pitch. The westerly dips occur in one of the subordinate schist masses, which forms a high cliff west of Cheshire reservoir, and again in a low knoll of schist at the extreme south limit of the map, near Berkshire village, and in a similar knoll south of Constitution hill and west of Lanesboro. Besides these there is one isolated observation between Lanesboro and New Ashford, and two others on Ragged mountain. So that the observations indicate an *almost universal easterly cleavage dip on Greylock.*



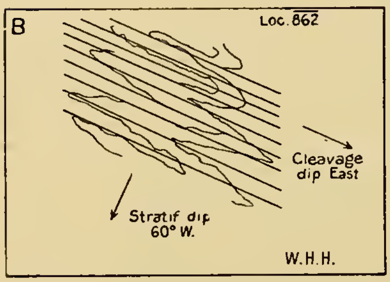


FIG. 57.—Diagrams showing the relation of slip cleavage to stratification at locality 55, north side of Mount Williams, and 862, ridge south of Sugarloaf. Cleavage parallel to axial planes of plications.

The question may well be asked how this can be, since the cleavage is so largely associated with the faulting of minute plications in strata which sometimes dip east and sometimes west. The observations indicate that where the sides of a fold dip in a direction opposite to that of the cleavage the axial planes of the small plications are generally parallel to the cleavage planes, and in extreme cases the faulted limbs of the plications lie in those planes (see Fig. 56). Fig. 57 represents this structure diagrammatically, as drawn in the field. Where the cleavage foliation and stratification foliation both dip in the same direction, but at different angles, the structure described in Figs. 56, 57 does not occur, and the slip cleavage planes are then either parallel with one or with neither of the limbs of the plications as in Fig. 59, or else there is a combination of an extreme form of slip cleavage bordering on slaty cleavage and of the coarse structure, described in Case VI, Fig. 48, and seen also in Fig. 58, in both of which the coarsely plicated quartz laminæ are more or less independent of the cleavage foliation. Or, the cleavage

FIG. 58.—Diagram of part of north side of schist ledge, locality 32, west side of Deer hill, area 7×5 feet, showing coarsely plicated quartz laminæ traversing the schist, which has a cleavage bordering on slaty cleavage.

foliation, as such, may disappear altogether, becoming merged in the stratification foliation. Thus, at the south end of Ragged mountain, there is a minor syncline, on the east side of which the cleavage has a high easterly dip crossed by plications dipping 90°, or west, at high angle, while on the west side of this syncline the stratification foliation dips 25° to 30° east and no distinct cleavage foliation is visible. (See Fig. 62.)

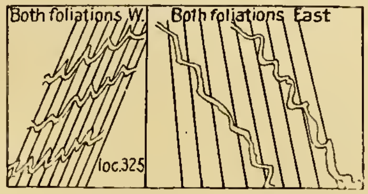


FIG. 59.—Diagrams showing relation of cleavage to stratification in schist where both foliations dip in same direction; cleavage parallel to one or neither limb of plication.

PITCH.

Early in the work my attention was directed by Prof. Pumpelly to methods of detecting the pitch of the axes of folds. Observations of pitch were made in fifty-four localities on Greylock, East, and Potter mountains. In a few places minor pitching folds are exposed, as in the limestone at the south base of Sugarloaf mountain (Fig. 60). But pitch was usually determined by observing the pitch of the axes of the plications of any part of a fold. The angle varies from 5° to 45°, but generally is not over 30°. In one or two instances it was over 45°. The correctness of the method seems to be verified by the general parallelism which exists between the minute and general structure of these rock masses, and also by the opposite direction of the pitch as thus determined, at the extreme ends of the mountain.[1]

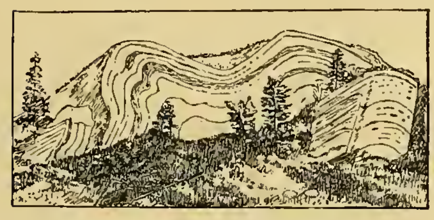


FIG. 60.—Minor limestone folds with a northerly pitch, south foot of Sugarloaf, New Ashford. Rock 50×30 feet.

STRUCTURAL PRINCIPLES.

From the foregoing data the following structural principles may be laid down as applicable primarily to the study of the metamorphic rocks of Mount Greylock, and then to a large part of the Taconic region and to similar rocks and regions.

[1] See, on the subject of pitch, Geo. H. Cook, Geology of New Jersey, Newark, N. J., 1868, p. 55; on the inclination of the axes of the flexures in the Taconic region, J. D. Dana, Taconic Rocks and Stratigraphy, Part 2, p. 399, already cited.

The lamination in schist or limestone may be either stratification foliation or cleavage foliation, or possibly a combination of both. False bedding occurs in limestone also. Therefore the conformability of two adjacent rocks is only shown by the conformability of the stratification foliation of both.

Stratification foliation is indicated by: (*a*) the course of minute plications visible to the naked eye, (*b*) the course of the microscopic plications, (*c*) the general course of the quartz laminae whenever they can be clearly distinguished from those which lie in the cleavage planes.

Cleavage foliation may consist of: (*a*) planes produced by or coincident with the faulted limbs of the minute plications, (*b*) planes of fracture resembling joints on a very minute scale, with or without faulting of the plications, (*c*) a cleavage approaching "slaty cleavage," in which the axes of all the particles have assumed either the direction of the cleavage or one forming a very acute angle to it, and where stratification foliation is no longer visible. These forms may all occur in close proximity.

A secondary cleavage, resembling a minute jointing, occurs in scattered localities, and, although not yet very satisfactorily observed on Greylock, original cleavage foliation may become plicated by secondary pressure.

The degree and direction of the pitch of a fold are often indicated by those of the axes of the minor plications on its sides.

The strike of the stratification foliation and cleavage foliation often differ in the same rock, and are then regarded as indicating a pitching fold.

Such a correspondence exists between the stratification and cleavage foliations of the great folds and those of the minute plications that a very small specimen, properly oriented, gives, in many cases, the key to the structure over a large portion of the side of a fold.

STRUCTURAL TRANSVERSE SECTIONS.

On these principles twelve complete and three partial transverse sections have been constructed across the Greylock mass; there are also three across Stone hill, to which reference will be made in Appendix A. All of these are on the same vertical and horizontal scale.[1] The first section, A, crosses the north end of the mass at North Adams; the last, O, toward its south end, between Cheshire and Berkshire villages; and the others at more or less regular intervals between. See map (Pl. I) for section lines, and Pls. XVIII–XXII, for sections.

The sections show that the range consists of a series of more or less open or compressed synclines and anticlines, which, beginning near North Adams, increase southerly in number and altitude with the increasing width and altitude of the schist area, and then, from a point about a mile and a half south of the summit, begin to widen out and diminish in number and height until they finally pass into a few broad and low undulations west of Cheshire.[2] Between that point and the villages of Lanesboro and Berkshire the folds become somewhat sharper and more compressed, and the schist mass rapidly narrows. The most comprehensive and best substantiated of these sections are those two which, beginning near South Adams, cross the central ridge north and south of the summit and then follow the two great western spurs and end near South Williamstown. These sections will now be described in detail.

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[1] Prof. E. Emmons (American Geology, vol. 1, p. 19) gave a section of Greylock running from Cheshire harbor, across the summit, and Mount Prospect, to Sweet's Corners and Stone hill.

Prof. James Hall's section, from Petersburg to Adams, made between 1839 and 1844, but unpublished, showed the synclinal structure of Greylock.

Prof. E. Hitchcock (Vermont Report, vol. 2, pl. 15, fig. 5) gave a section similar to, but less detailed than that of Emmons. Both of these are drawn on a greatly exaggerated vertical scale, and represent the mountain as a simple syncline.

Prof. J. D. Dana, in his paper on "Taconic Rocks and Stratigraphy" (p. 405), reproduces Emmons's and Hitchcock's sections, and adds several fragmentary ones of his own. On the east side, one west of North Adams (Fig. 47), another west of South Adams (Fig. 44); on the west side, one on the west flank of Mount Prospect and north of the Hopper (Fig. 45), and another on the south side of the Hopper (Fig. 46); all of which simply represent the relations of the schist to the limestone on either side of the syncline, along the base of the mountain. In his paper on the "Quartzite, Limestone, and Associated Rocks of Great Barrington," etc. (1873, p. 273); and again in his paper "On the Relation of the Geology of Vermont to that of Berkshire" (1877, p. 263), he conjectures from the north and south trend of part of the "Hopper" depression that the Greylock syncline comprises one or more subordinate folds.

[2] The sections have all been carried down to the top of the quartzite which underlies the Stockbridge limestone. The observed dips have also been indicated on them to enable the reader to distinguish between matter of actual observation and of ordinary induction. The cleavage dips have been similarly indicated, but on a separate line, and the cleavage foliation has also been shown on the drawings crossing the stratification wherever both were observed, but it doubtless traverses the greater part of the mass.

TRANSVERSE SECTION G.

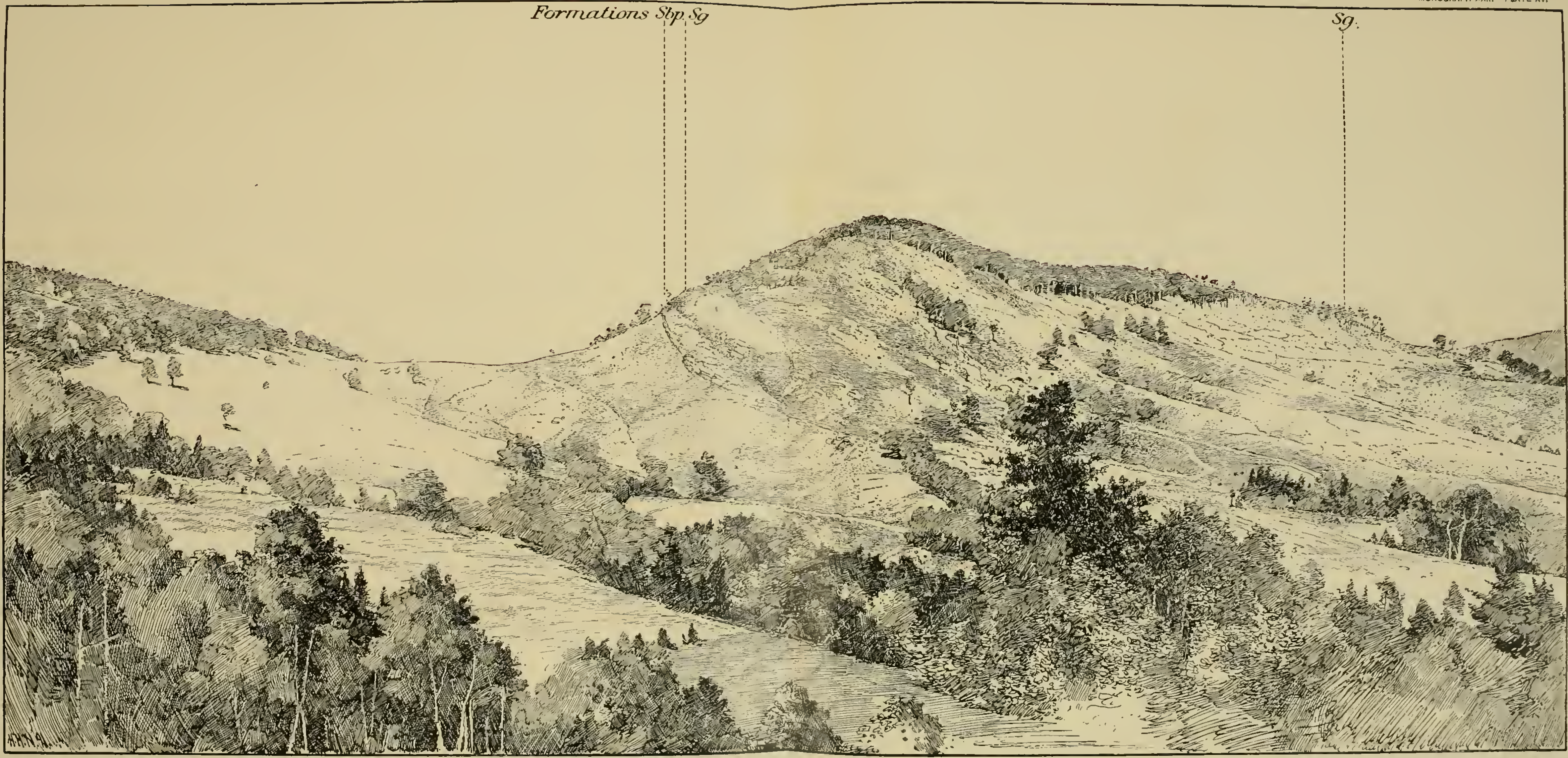
From the Hoosic river at Renfrew mills (South Adams) across Ragged mountain, the central ridge, Symonds peak (Mount Prospect), and the north end of Deer hill See Pl. XX and Fig. 61.

Between the most easterly and the most westerly outcrops in the limestone area along the east foot of Greylock there is a syncline followed westerly by an anticline. This is corroborated by observations about the quarries a quarter of a mile north. The well-known relation of the limestone to the schists farther up the mountain is not shown here, but may be seen on Section B, Pl. XVIII, about 1½ miles south of North Adams, locality 28, where the limestone, after forming a very small anticline, ruptured and partially eroded, dips, a few feet west of it, at an angle of 15° to 30° west, conformably under the schist, both rocks striking north 25° east.

Above, the Hoosic valley limestone comes a mass of schist which forms the lower, more precipitous, and wooded slopes, and which, along this

FIG. 61.—Section G, from the Hoosic river across Ragged mountain, the Central ridge, Symonds peak (Mount Prospect) and Deer hill.

section, dips west at an angle of about 30°. Above these schists is a bench of arable land stretching for several miles along the east side of Ragged mountain. This mountain forms the higher portion of the northern end of the range as seen from Hoosac mountain (Pl. XII), but is separated from the central crest by the "Notch," the south end of which is called the "Bellowspipe," from the prevalence of wind there. (See Pl. XVI.) This bench on the east of Ragged mountain measures about 600 feet in width and is marked by outcrops of a micaceous limestone which here dips 70° to 75° west. The bench seems to owe its agricultural value in part to the rapid decomposition and soil-forming quality of this rock, and probably in part also to the fact that this more deeply eroded strip of the mountain flank has formed a receptacle for sand and soil which would have been drained off a steep slope. At several points on the west side of the bench the micaceous limestone comes in close proximity to another mass of schist, but the upper contact is covered on this section. At localities 838, 839, Sec-



SOUTHERN END OF RAGGED MOUNTAIN.

Seen from locality 190, about one-half mile south, showing the easterly dipping Greylock schist (Sg) in contact with the Bellowspipe limestone (Sbp) on the west side of Ragged mountain, and the saddle (4 birds) due to the erosion of the limestone anticline (Sbp). The hollow to the left is the Bellowspipe. The pasture land on the right corresponds to another area of Bellowspipe limestone. From a photograph.

tion E, Pl. XIX, both rocks dip west, and at 669, Section F, both are Horizontal, the limestone underlying the schist in all cases.

In ascending the east side of Ragged mountain over this second mass of schist only westerly dips are met, but on Sections E, C, and again about a mile south of Section G (localities 204, 126) there are some well-observed eastern dips following westerly ones and indicating a syncline, which, probably being less open at this end of Ragged mountain, escapes observation. Near the top is a narrow belt of calcareous schist forming a north to south ravine across the ridge and connecting the limestone area of the Notch with that on the south. Beyond is a small, isolated schist area which forms the south end of the top of the Ragged mountain ridge. The dips continue westerly. In descending into the Notch the calcareous schist recurs, dipping 60° east and indicating another syncline. The syncline of this small schist area is best seen about a half a mile south of the section line, and has already been referred to on p. 157. (See Fig. 62.) On the east side of and close to the schist, the calcareous schist (plicated) dips 90° and west at high angle; the schist (feldspathic and chloritic) is also plicated in the same direction, with a high, easterly cleavage. Again, at locality 733, about 500 feet south of the section, the two rocks come in contact with westerly stratification foliation and easterly cleavage. On the west side of this schist area both rocks are in contact in inverse order, dipping east at a low angle. These easterly dipping beds of the west side of Ragged mountain stand out in prominent ledges which can be clearly seen from the top of a knoll (locality 190) about half a mile south of the Bellowspipe. (See Pl. XVI.) The same syncline occurs on Section F and also continues south of Section G, on the knoll just mentioned, in the limestone and calcareous schist area. This limestone is very pyritiferous in places; an assay of the pyrite, said to have yielded a small percentage of gold, led re-

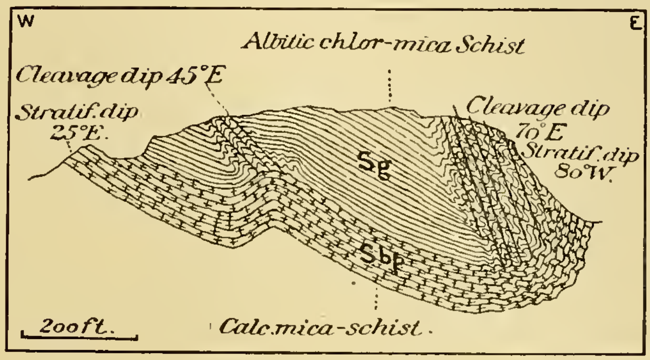


FIG 62.—Section of small syncline at south end Ragged mountain, showing relations of the foliations in the east limb. This section crosses lower part of central mass shown in Pl. XVI.

cently to some tentative mining here. From the occurrence of the small belt of calcareous schist across the top of Ragged mountain and from the presence of a well-marked syncline in the western part of the small schist area, the structure here has been construed as consisting of two minor folds.

The section now crosses the "Bellowspipe." Dip observations both north and south of the line (see map, Pl. I), indicate an anticline here. The contact on the west side of the Notch is covered, but along Section F (locality 709) the micaceous limestone dips west, and the overlying feldspathic schists occur a few rods west of it with a similar dip. Some 800 feet south of this (Section G, locality 589), a quartzite, which frequently replaces or is interbedded with these calcareous beds, dips 60° west ; and in ascending the hill the nearest outcrop of schist (locality 591), about 500 feet west, also dips west. The relations which occur on the bench on the east side of Ragged mountain are thus repeated on the east side of the central ridge.

The section now crosses the schists of the central ridge about 1 mile north of Greylock summit and about a half mile south of Mount Fitch. The low westerly dip was observed at several points along the Greylock road north and south of this section and also at 831 south of Section E. The section then descends into the north fork of the Hopper depression. The high westerly dip occurs in the precipitous ravine which, beginning about a quarter of a mile north northwest from the summit, finally opens into the north fork of the Hopper. Along the 2,100 to 2,200-foot contour and extending down to about the 1,900-foot contour, on the west side of the central crest and in this north to south portion of the Hopper, is a belt of calcareous schist similar in character to that on both sides of Ragged mountain, but less calcareous. Farther south, west of Saddle Ball, this rock passes into the micaceous limestone. At several points westerly dips were found in this belt. It does not recur westward in this portion of the Greylock area. From these facts the central crest has been construed as a syncline of schist with a steep west side, a gently sloping east side, underlaid by the limestone and calcareous schist of the Notch and the Hopper.

Mount Prospect (Symonds peak, see Pl. XVII), consists of an anticline, with some minor undulations on the east side and a syncline on its west face. This is confirmed by observations on Section E and also on Bald Mountain, Section I, Pl. xx. The presence of the lower limestone on the west face of Mount Prospect and of the calcareous schist belt in the Hopper, east of it, indicates that its schists correspond to those which, on the east side of the range, intervene between the lower limestone (Stockbridge limestone) and the calcareous benches. On the west side of Mount Prospect (locality 1020), near the contact of the schist with the limestone, there are alternations between the two rocks probably due to the erosion of some minor folds.[1] The contact here with the limestone occurs along the 1,600-foot contour, while at the east end of this section it occurs between the 1,200 and 1,300-foot lines, a fact already noticed by Prof. Dana.

Between the schist boundary on the west side of Mount Prospect and the Hopper brook is an area about a mile wide, in the eastern half of which there are numerous outcrops of limestone, but the western half of which is covered with drift. There is however little doubt, judging from the outcrops north and south of the section, that this area is also underlaid by limestone, and, if so, that it forms several minor folds. (Compare Section I.) It is in the limestone at the foot of Mount Prospect and near the mouth of the Hopper that Mr. Walcott observed "several traces of fossils," one of which, he says, "appears to be the inner whorl of a gasteropod related to *Euomphalus* or *Maclurea*.[2]

Along the Hopper brook, about a quarter of a mile above its junction with the Green river, is a small area of quartzite long ago noticed by Dewey and Emmons and also referred to by Dana.[3] In Emmons's section,

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[1] Such interbedding or minor folding near the line of contact occurs also west of Pittsfield on Hancock mountain, in the Lebanon road.

[2] Chas. D. Walcott: The Taconic system of Emmons, and the use of the name Taconic in geologic nomenclature. Am. Jour. Sci., ser. III, vol. 35, March, 1888, p. 238.

[3] Dewey: "On the stream which issues from the Hopper is arenaceous quartz of a slaty structure, which is an excellent stone for sharpening the chisels used by stonecutters." Am. Jour. Sci., ser. I, vol 1, 1819, p. 341.

Emmons: "The outcrop of the quartz occurs again two miles south, near a mill at the junction of the Hopper creek and Green river. A small part only of the mass is exposed, dipping southeast and towards the high range of mountains known as Saddle mountains and Greylock." Am. Geology, vol. 1, part 2, pp. 12–13.

Dana: "The quartzite of Stone hill and the quartzitic mica schist of Deer hill in Williamstown may be either of the upper or lower quartzite formation, if judged only by the facts the hill presents. But the position of these areas, in the Williamstown valley, between high ridges of hydromica schist, suggests rather that it is the underlying Cambrian." Am. Jour. Sci., ser. III, vol. 33, May, 1887, p. 410.

already referred to, this quartzite, interbedded with mica schist, is represented as dipping conformably under the limestone of the west side of Mount Prospect and as separated from the limestone area of the Williamstown valley west of it by a fault.[1] This he also represents in another section (Geology Second District, p. 145, Fig. 46). The outcrop in the river dips about 30° eastwardly, but a few rods southwest up the bank (locality 11) the quartzite has vertical plications traversed by joints dipping south or southwest. Mr. J. E. Wolff finds considerable detrital feldspar in this rock, which distinguishes it from the feldspathic schists of Greylock that overlie the limestone and ally it to the Stone hill quartzites. Mr. Wolff's report on this rock reads as follows:

"Specimen 1092*a*. Slide: a fine-grained aggregate of quartz and feldspar. Stringers of muscovite give to the rock a schistose structure. The feldspars occur in irregular, angular grains, part unstriated, part striated, part microcline. The mica and quartz often so surround and cut across these grains as to suggest secondary origin of the former. Some of the feldspars contain cores of twinned plagioclase feldspar, surrounded by a rim of untwinned feldspar, or else a core surrounded by a rim of feldspar in a different orientation, suggesting perhaps secondary enlargement. It seems probable that the feldspar in this and similar rocks is clastic (angular shape, different varieties in same rock, etc.) It is noticeable that they do not contain quartz and mica belonging to the groundmass, as the porphyritic feldspars of the feldspathic schists of Greylock often do, suggesting a difference in origin. Tourmaline needles occur."[2]

When in addition to this we take into consideration the fact that 2 miles south of this locality, on Section I, there is evidence of faulting, little doubt remains that these quartzites correspond to those of Stone and Oak hills, and are not to be considered as quartzose beds of the Deer hill schists, which are evidently continuous with those on the south side of the Hopper and overlie the limestones.

At the Sweet's Corner dam, about a third of a mile north of Section G, the foliation (stratification or cleavage) of the schist strikes north 7° to 12°

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[1] Emmons: "Along the base of this mountain [Prospect] is a fracture whose direction is nearly north and south, and the limestone forming the valley was severed from that of the mountain side by an uplifting force." Report on Agriculture, p. 80. See also Geology Second District N. Y., p. 157, and E. Hitchcock, Report Geol. of Vermont, vol. 2, p. 598.

[2] Compare Appendix A, p. 200.

east, and dips 30° to 35° east. Immediately east of the bridge the land rises 40 to 50 feet, forming what is called Sawmill hill. In the schist along the foot of this hillock the cleavage strikes north 7° to 10° east, and dips 50° to 60° east, but plications are visible here and there, striking east or northeast, and dipping south or southeast. The same is true of the outcrops farther up the hill. These observations are confirmed by those at locality 1098, at the north end of Deer hill, along the Green river, where the schist plications dip 45° southeast and are crossed by cleavage planes dipping 40° east in one place and in another 70° east. On the top of the hillock the most northerly outcrop is limestone with somewhat curved strata, striking north 5° east, and dipping 35° to 40° east, underlaid 30 feet west by schist, with a foliation (cleavage) having a like dip. About 100 and 140 feet south of this limestone outcrop there are two small masses of the same rock with coarse, steep westerly or vertical plications. These may be ledges. From all this it has been inferred that the schists of Sawmill hill, instead of underlying the limestone as represented in Emmons's section, are continuous with those of Deer hill, and overlie the limestone; that the superposition of the limestone is the result of an overturn and a fault which have caused the schist to dip southeast and the really underlying limestone to overlie it with an eastern dip; and that this fault reappears southward, on the east side of Deer hill, where it has brought up the Oak and Stone hill quartzites, which underlie the limestone, to the level of the schists which overlie it, causing a displacement of about 1,400 feet.

The section now traverses Deer hill. On the northwest side of the hill, at the Green river, layers of calcareous schist with blue quartz alternate with a calcareous, ferruginous quartzite, all dipping 40° east. Their exact stratigraphic position is not determinable, but as they are separated from the Stone hill quartzites by a considerable area of limestone, as there is no evidence of a fault there, and as the schists of Deer hill clearly overlie the limestone at localities 7, 8, and 630 on the west, these particular layers have been regarded as representing simply a transition from the lower limestone to the lower schist. The portion of Deer hill traversed by Section G has for these reasons been construed as a syncline, with a fault on its eastern side.

TRANSVERSE SECTIONS H, I.

From the Hoosic river above Maple Grove station (South Adams) across the central ridge, Bald mountain, and the south end of Deer hill, to the Green river. Also Section H, across the summit (see Pl. XX and Figs. 63, 64).

The observations east of the central ridge along this section are few and unimportant. The lower schist belt measures about half a mile in width, and the area of the overlying limestone and calcareous schist about a mile in width. The latter is not overlain here by a subordinate mass of schist corresponding to Ragged mountain, but extends uninterruptedly, and probably in a series of very gentle undulations, up to the base of the cliffs which form the east face of Greylock proper. The contact between the two rocks, wanting on Section I, can be seen in Peck's brook on Section J, the calcareous schist underlying the feldspathic, non-calcareous, micaceous, and chloritic schist, both with a westerly dip. On the face of the cliff, locality 549, the cleavage foliation dips 65° east, and the stratification foliation 15° to 25° west, and low west or horizontal dips prevail to the summit. (See Section H, and Figs. 44, 46, 53, 54.) At the top of the ridge which forms the seat of the saddle between Greylock and Saddle Ball and so also just west of the Greylock summit the dips are high east. The structure of the top of the central ridge here has thus been construed as a minor syncline with a steep east slope on the west side and a gentle west or horizontal one on the east side.

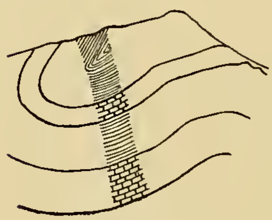

FIG. 63.—Cross-section H.

The section line now descends a little north of Shattuck flats to the

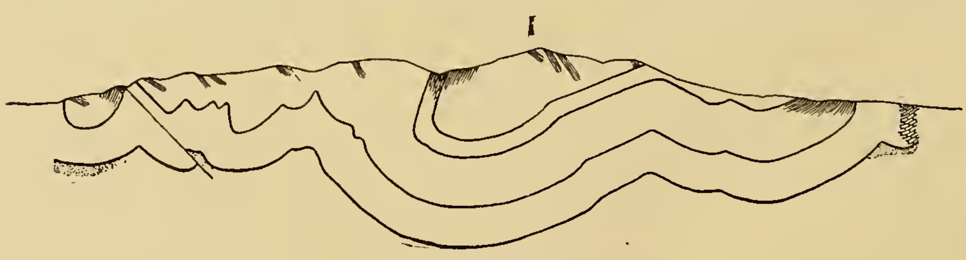

FIG. 64.—Cross-section I.

south fork of the Hopper brook. The observations above the flats are not conclusive, but in the most southerly ravine, tributary to the south fork of the Hopper, westerly dips occur, as they do also in the ravine running north northwest from the summit, which cuts deeply into the central crest, and which has already been referred to under Section G. This west dip is also shown on Subsection H. The calcareous schist belt is crossed again and recurs south in one of the forks of Goodell brook, in both cases with a westerly dip. All this leads to the same interpretation as in Section G, excepting that a small anticline seems to intervene here between the summit and the calcareous belt, the compressed syncline of the central crest having in it a minor fold which does not appear on Section G.

The section then crosses Bald mountain. Here a great surface of the lower schists is exposed. A high northeasterly dip is well determined at locality 95 (see Fig. 41), and corroborated at locality 242 on the southwest side of the mountain, both with a strike of north 40° east (see Case VII, p. 150); and an easterly dip recurs high up on the east side of Mount Prospect. East of this locality the dip is east in places, but there are probably minor folds and much thickening. On Section J, Pl. XXI, which passes along the south side of Bald mountain about 500 feet below its summit, horizontal or low west dips occur, striking with the much steeper dips of the top, and probably representing the lower and broader part of the Bald mountain syncline. East of this, in the Goodell hollow ravines, there are high westerly dips. These facts, and the situation of the calcareous belt in the Hopper, have rendered necessary the peculiar construction seen in the section. Bald mountain thus consists on the east of a sharp anticline turned over to the east, followed on the west by a syncline which probably consists of minor folds.

West of Bald mountain, along the spur between the line of the strike of locality 242, on the east, and localities 106 and 645 (Hopper), on the west, there is an anticline corresponding to the one at the top of Mount Prospect followed westerly, between localities 218 and 217, by a syncline corresponding to that on the west face of Prospect. West of this again, between localities 117 and 217, such a succession of westerly dips occurs that it has been necessary to insert a conjectural compressed syncline and anticline in order to explain the dips as well as the absence of the lower limestone. From the dips in the limestone and schist in the Hopper on the northern side of the spur it is probable that another small anticline occurs between localities 115 and 117 on the spur. In fact, judging from the many alternations in the dip and the absence of the lower limestone, the whole spur west of Bald mountain seems to consist of a series of minor folds whose number probably varies but slightly from that represented in the section. Fig. 56, p. 155, represents a specimen from locality 115 on this portion of the section. In constructing the section the depth of the limestone has been governed by the angle of pitch along the spur and the relations of the Hopper and Mount Prospect (Section G) to Goodell hollow (Section J).

About three-quarters of a mile east of that arm of the Green river known as Ashford brook the section crosses a hill known locally as "Pine Cobble." On the west side of it is a small limestone area cut off by schist: on the north, from the Hopper limestone area, on the south from the New Ashford limestone area, and on the west from the South Williamstown limestone area. On the east this limestone underlies the Bald mountain schists conformably, but on the west side it is unconformably underlaid by schist, owing to a fault, the character of which has been partially described under Case x, Fig. 55. There would seem to have been a sharp ruptured anticline here, the eastern limb of which, consisting of the upper 400 feet of the lower limestone, with the overlying schist, was thrown up, while the western part slid under the limestone, the break having occurred along the eastern limb of the anticline in the upper part of the limestone bed. This fault strikes with the fault along the eastern side of Deer hill and at Sawmill hill, already described, and with the one referred to by Emmons. The displacement here can not well be less than 500 to 600 feet. The structure of the entire spur also indicates a great deal of compression.[1]

West of the fault the schist dips high west, or 80°, and on the west side of Deer hill, a little north of this section, the limestone of the South Williamstown valley occurs in contact with and under the schist, both rocks dipping east. On the east side of Deer hill the dips are 90°, or west, indicating a synclinal structure for the central portion of that hill.

A small ravine skirts the west brow of Deer hill, the east side of which is formed by a cliff of schist, the west by a low ridge of limestone. At

[1] At locality 331, on west side of Sugarloaf, about 3½ miles south of this part of Section I, there is an anticline turned over to the west, bringing the schists under the limestone; and there are some indications of a fault between them, but the evidence is not conclusive.

locality 32, a little south of east from South Williamstown village, the structure of the schist is finely exposed (see Fig. 58), the coarse stratification foliation (plications) dipping about 45° east with a southerly pitch, associated with a cleavage foliation dipping 35° east. Following this ravine southerly, its sides gradually approach each other until the two rocks are finally found in superposition with a westerly dip.

The chief points of interest in the remaining sections will be only briefly referred to.

TRANSVERSE SECTIONS A–F, J–O.

Section A, Pl. XVIII, crosses the northernmost portion of the range at North Adams, and shows a compressed syncline turned over westward.[1] The actual contact may be seen about a thousand feet west of the North Adams railroad depot, the limestone overlying the schist, both rocks striking north 22° east, and dipping 45° southeast. I failed with careful search to find any quartzite outcrops in this part of Greylock, although there are numerous bowlders of it which have probably been brought from Clarksburg mountain or beyond.[2] There is room, between the lowest outcrop of quartzite on Clarksburg mountain and the western side of the steep portion of the Greylock mass traversed by this section, for a bed of limestone 1,400 feet thick dipping at an angle of 50°, which is the dip of the schist at locality 916 (see map); and none of the measurements of the thickness of the lower limestone obtainable on Greylock indicate a greater thickness than that.

Section B, Pl. XVIII, about a mile and a half south of North Adams. The limestone of the Hoosac valley and the schist of Mount Greylock appear here in their normal relations. The syncline which farther south constitutes the central portion of Ragged mountain appears; and there is a second syncline west of it, identical with the one on Section A, but open, and also with that on the east side of the Notch. In the western portion of the section two synclines and an anticline have been conjectured from observations farther south. It will be observed that this section crosses the Greylock mass below the horizon of the upper limestone and calcareous schist.

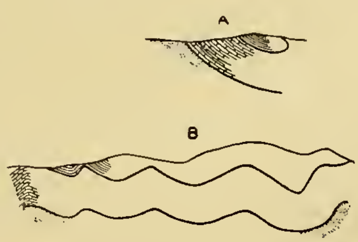

FIG. 65.—Cross-sections A, B.

Section C, Pl. XVIII, about 2 miles south of North Adams. The calcareous bench

[1] See J. D. Dana, Taconic Rocks and Stratigraphy, Sec. 47, p. 105. Also, On the Quartzite, Limestone, etc., of Great Barrington, p. 273.

[2] J. D. Dana, On the Taconic Rocks and Stratigraphy, p. 406: "A prolongation of it [the Clarksburg mountain quartzite] appears to extend south of Braytonville into the north end of the Greylock mass, along the ascending road (but chiefly on its eastern side) for a mile."

on the east side of Ragged mountain appears with minor undulations. A well-marked syncline forms the top of that mountain; on its west side the calcareous belt is crossed twice with an intervening tongue of the underlying schist, necessarily anticlinal in structure. At the west end of the section there is what might easily be *mistaken for unconformability* between the limestone and schist, a foliation in the limestone (at localities 1035, 1036), striking north 77°–80° east and dipping 25°–50° south, while the plications in the schist close by and higher up (locality 1038) dip westerly with a southerly cleavage, conformable to the foliation in the limestone. It is highly probable that the foliation in the limestone is cleavage, and that a stratification dipping west conformably to the plication in the schist has been obliterated. This would make a syncline with the limestone underlying, as in the section.

Section D, Pl. XVIII, nearly half a mile farther south. The Ragged mountain syncline continues with the upper limestone dipping under it. On the north side of Mount Williams there is a bench circling around from "Wilbur's pasture" (the saddle of this Saddle mountain), at the south end of the north to south part of the Hopper, and continuing into the Notch. The eastern part of this bench is visible from the north end of Ragged mountain. Along this bench probably passes Formation Sbp—here, however, without any outcrops that are calcareous, except at 641 and 645 on the north-northwest side of Mount Williams. The presence of masses of non-calcareous schist measuring from a quarter to three-quarters of a mile in length and several hundred feet wide on the northeast side of Ragged mountain and on the southwest side of Saddle Ball in the upper limestone and calcareous schist, and the fact that in the Hopper the strata of this horizon are much less calcareous and more micaceous than at the south end of Saddle Ball or in the Notch, and, finally, the presence of noncalcareous quartzite as well as limestone in the same horizon in the Notch, all indicate the very changeable lithologic character of this horizon. Furthermore, the general synclinal structure of the central ridge, the presence of a calcareous belt on both sides of it, and the similar constitution of Ragged mountain, together with the fact that at both ends of that mountain the calcareous belts are connected, and the greater difficulties involved in any other construction of the central crest, all lead to the interpretation given in the map, and in this, as well as the other sections. Section D traverses Mount Williams a little south of this belt of Formation Sbp. The basis for the remaining features of this section will be found largely in the next one.

Section E, Pl. XIX, crosses Ragged mountain, Mount Williams, and the north end of Symond's peak (Prospect mountain). The Ragged mountain syncline passes east of the top of that ridge. Along the east base of Mount Williams a long ledge of schist shows plications dipping 40°–45° west, crossed by an easterly cleavage dipping 60°. These west dips on the east side and the higher westerly dips on the west side of Mount Williams indicate the character of the syncline of the central ridge seen farther south on Section G. The high westerly dips on the top of Mount Prospect (north end, or

Saddle mountain, localities 619, 621,) are construed as indicating a structure similar to that on Section G on the same mountain, but more compressed. The presence of an area of level arable land measuring about 1,000 feet square—"Wilbur's pasture"—at an altitude of 2,200 feet above sea level between the schist masses of Symonds peak on the west and of Mount Williams on the east, forming the saddle of this Saddle mountain, and corresponding, as it does, to the similar area, "Shattuck flats," about 2½ miles south, between Bald mountain and the central crest, at an altitude of 2,500 feet, and also to the calcareous bench on the western and southern side of Saddle Ball between the 2,200 and 2,500 feet contours, together with the occurrence of the calcareous belt between Wilbur's pasture and Shattuck flats in the Hopper ravines, all point to a structural if not to a lithologic similarity. (See Pl. XVII.)

Section F, Pl. XIX, is confined to Ragged mountain. The syncline and anticline observed about the limestone quarries between Zylonite (Howlands) and Renfrew, on the mountain side, appear here. The lower schists measure only about 1,000 feet on the east side of Ragged mountain at this point. In the centre of the Notch, locality 632, highly contorted strata of a feldspathic quartzite with a low southerly pitch occur. The occurrence of a similar rock is so frequent in this belt that it may be said in part to characterize the horizon.[1]

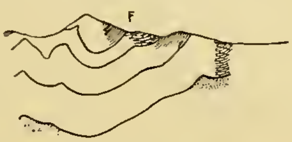

Fig. 66.—Cross-section F.

Section J, Pl. XXI, south of Section I, from a point a quarter of a mile south of Maple Grove station (South Adams), crosses a lens-shaped compressed syncline of the lower schist, which is here very graphitic, as it is frequently near the lower limestone. At the contact, on the east side, the schist seems to inclose large lenticular blocks of the underlying limestone. West of the main belt of the lower schist is an area, nearly 2,000 feet wide, of a rock resembling the feldspathic quartzite of the Notch, referred to under Section F, but so micaceous as to constitute a fine-grained gneiss.[2] The strata dip west, and appear to overlie the adjoining schists. For these reasons this area has been considered as forming part of the upper limestone belt. The observations at the west end of this section in Goodell hollow on the south side of Bald mountain have already been referred to under Section I. Dip observations taken at different elevations indicate that the folds become more acute in the lower as well as the higher parts of the mass.

Sections K, L, Pl. XXI, commence north and south of Cheshire harbor. The schist mass east of Cheshire harbor on Section K, which sends out a tongue southwards, crossed also by Sections L and M, is that represented in Emmons's section as underlying the Hoosic valley limestone, and corresponding to the schist of Sawmill hill near Sweet's corners. But observations made by other members of this division of the geological survey along the base of Hoosac mountain show that this schist mass

[1] Mr. Wolff's determinations of this rock are given on p. 185 (locality 345).
[2] See p. 186, specimen from locality 616.

probably overlies the Hoosic valley limestone. Along sections K and L there is difficulty in tracing the connection of the upper calcareous belts of both sides of the central ridge, owing to the absence of outcrops on the west side of Saddle Ball. The central ridge (Saddle Ball) there slopes off to the east at an angle of about 10°, forming a bench which is even less inclined than that on the west flank of the mountain. See the view from Lenox mountain, Pl. XV. The conjectural track of Horizon Sbp. which on the map joins the outcrop of micaceous limestone at the south end of Saddle Ball ("Jones's Nose") with those in Peck's brook, Section J, has been drawn to conform to the strike and trend of the central ridge, and to those of the calcareous belt on its west side. It is based on both structural and topographic considerations. (Compare the remarks on Section D.) On the west of the mountain and about Gulf brook there are calcareous schists separated from the upper calcareous belt by non-calcareous schists. These have been thrown into the lower schists as probably repre-

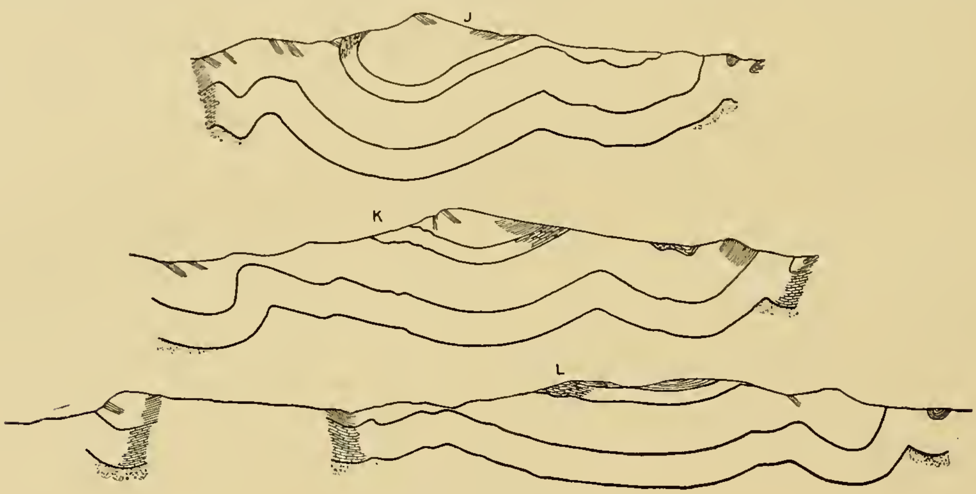

FIG. 67.—Cross-sections J, K, L.

senting mere transitions from the lower limestone to the lower schist, such as were observed at several localities over small areas (Deer hill, 630; Lanesboro, 365; New Ashford, 530), and are thus regarded as only indicative of the proximity of the lower limestone.

In Section L the opening out of the compressed and overturned fold of the central ridge into a very broad and open syncline is seen. The calcareous belt of the Hopper becomes here a gently sloping bench of arable land nearly a quarter of a mile wide, once dotted with farms, and still used for pasturage. (See Pl. XIV.) The rock becomes much more calcareous, and dips east at a low angle under the upper schists of the central ridge, and bends around eastwardly between Saddle Ball and Round rocks, the former consisting of the upper and the latter of the lower schists. The upper schists form a cliff on the south side of Saddle Ball at the incision in the central ridge, which is seen so plainly from the Taconic range (Pl. XIII), and from East mountain (Fig. 74, p. 194). Here the strata are horizontal or dip very low east, and are crossed by a cleavage-foliation, as shown in Fig. 68. The section passes along the foot of these cliffs. The upper bench of Saddle Ball, shown in Section L in the upper schist, and also in the views (Pl. XIV and Fig. 74), does not correspond to any calcareous horizon. A quarter of a mile north it measures about 800 feet in width. Section L has been extended through East mountain, where the strike changes to north 40° to 50° east, crossing the trend of the hill, and a sharp syncline occurs in the schist with the limestone of the Hancock valley dipping under it on the west. This schist is continuous with the lower schist of the Greylock mass, but the outcrops did not yield further structural data. East mountain seems to be one of the subordinate folds of the Greylock synclinorium which would thus measure here nearly seven miles in width.

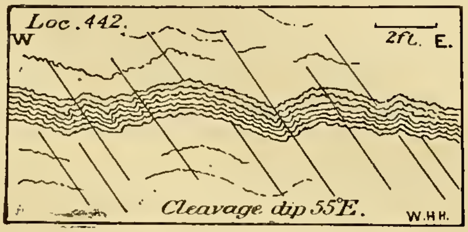

FIG. 68.—Structure in schist in cliffs on south side of Saddle Ball above the Bellowspipe limestone.

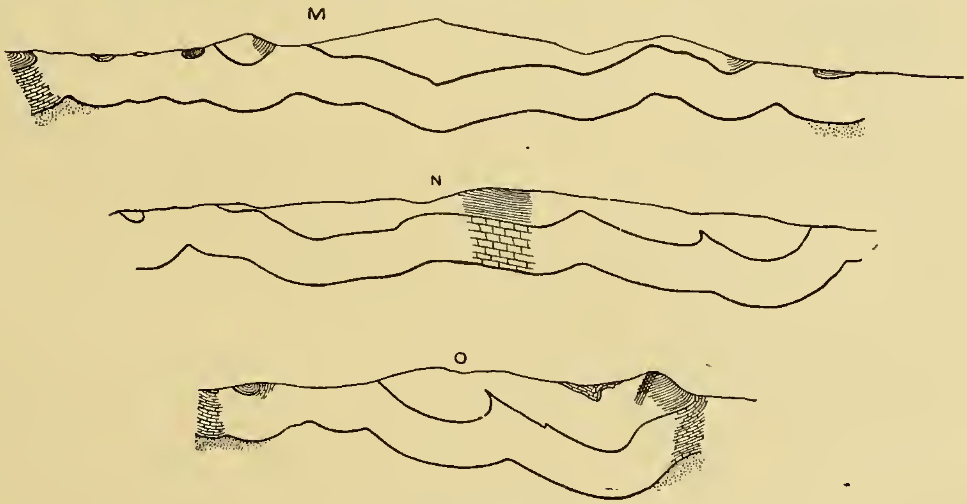

FIG. 69.—Cross-sections M, N, O.

Section M, Pl. XXI, begins about midway between Cheshire and Cheshire Harbor. The axis of the central syncline seems to continue in the lower schists across Round rocks, where a cliff about 1,000 feet long from east to west and 150 feet high shows low east dips at its west end and low west dips at its east end. (See Fig. 74.) East of this point observations were few and unsatisfactory. Farther west the section crosses Sugarloaf mountain, which is a small open syncline. (See Appendix B.) West of it a number of minor folds produce the frequent alternations of schist and limestone about New Ashford. The entire synclinorium here consists of a greater number of smaller folds. The section is below the horizon of the upper limestone.

Section N, Pl. XXII, begins at Cheshire and shows a syncline in the schist north of the Farnham's quarry limestone area. This syncline appears to be continuous with that of Sections K and L, and is also on the line of the Ragged mountain syncline. North of the Lanesboro limestone area there are indications of an anticline in the schist; and between this and the syncline on the east the numerous easterly dips are interpreted as indicating a compressed fold, inclined westward, between the central syncline and the eastern one. Between East mountain and the central Greylock ridge, in the western part of the section, minor undulations yield alternating areas of schist and limestone as on Section M. Both this and the following section indicate an increasing compression, the folds becoming more numerous, relatively to the distance, less open and more inclined than on Section L.

Section O, Pl. XXII, starting from Cheshire reservoir, crosses the Farnham's quarry limestone area. At the east foot of the high schist ridge, which presents its precipitous side to the Hoosic valley (compare Pl. XV with this section), the limestone evidently dips under the schist. At the south end and east side of this ridge the schist has a high westerly cleavage, and very low westerly or horizontal plications (localities 315, 427, 325½), together with a northerly pitch (locality 325). Toward the limestone on the west the westerly dip appears still to continue (localities 325, 410, 411). The structure at locality 315 is represented approximately in Fig. 70; that at locality 325 in Fig. 59, p. 156.

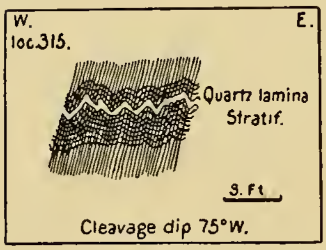

FIG. 70.—Structure in schist on the ridge west of Cheshire reservoir.

From the syncline north of the Farnham's quarry limestone area (Section N), from the northerly pitch south of it on Savage mountain, from the westerly dip in the schist east of that area, and the easterly dip of the same rock west of it (Section O), from the character of the dips in the limestone itself, as well as from the isolation of this limestone from that of the Hoosic valley, it has been inferred that a schist syncline underlies the Farnham's quarry limestone, and, therefore, that, although lithologically identical with the lower limestone, it belongs stratigraphically with the upper. We have here, apparently, a small limestone basin similar in structure and position to the larger one which surrounds and underlies Ragged mountain. The difference in the limestone of these two areas is mainly in degree of metamorphism. But in several places the limestone of Hoosic valley resembles that of the Notch. About half a mile SSW of the west end of this section (O), at the east foot of East mountain (locality 749, back of Mr. Pine's house), the schist apparently dips east, as does also the limestone. No plications are discernible. If this be the correct dip it indicates an overturn, the dips corresponding to those on the east side of Potter mountain (locality 984) and on the road from Pittsfield to Lebanon (locality 1020).

General pitch of the folds.—The observations of pitch are recorded on the map by a special symbol. It will be noticed that the direction of the pitch through the northern part of the central ridge is south, while at its southern extremity, west of Cheshire reservoir, it is north. Sugarloaf mountain, New Ashford, has a northerly pitch at its south end, and a southerly pitch at its north end. Ragged mountain has a southerly pitch at its north end, and the succession of the horizons at the surface and other facts indicate a northerly pitch at its south end. From the "Bellowspipe" the pitch is probably both north and south. In places a similar pitch seems to prevail along parallel lines across the central ridge as well as the subordinate folds; thus the southerly pitches on the Bald mountain spur, the northerly pitches on Potter mountain, Constitution hill, and the Noppet, and on Savage mountain in Lanesboro; again, the northerly pitch at Cheshire Harbor is undoubtedly repeated at Round rocks, although not observed there in the plications.

LONGITUDINAL SECTIONS.

The facts stated above are shown on the four longitudinal sections appearing on Pl. xxiii. Three of these, on a reduced scale, are given in Fig. 71. The north is at the right.

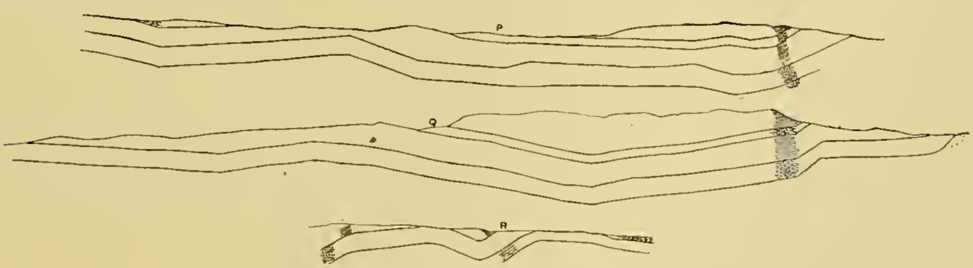

FIG. 71.—Longitudinal sections P, Q, R.

Section P follows for 12 miles the axis of the eastern or Ragged mountain syncline, beginning at the Hoosic river a little south of North Adams, between Cross-sections A and B. At the north end of Ragged mountain the upper limestone and the upper schist horizons are shown with the steep southerly pitch which marks the whole northern end of the Greylock mass (compare the symbols on the map). On Cross-section F there is a thinning of the lower schist. There are some indications of a northerly pitch on the east flank of Ragged mountain west of Howland's, between Sections F and E; but along the Notch brook the pitch is south like that on the Central crest (Section Q). The deeper part of the syncline is about under the center of Ragged mountain. The upper limestone rises to the surface about a mile south of the south end of this mountain with a gentle northerly pitch,[1] and about 1½ miles farther south the underlying schists also rise to the surface, forming the pinnacle and the neighboring schist masses which hedge in on the south the northern area of the upper limestone. South of this is the Farnham's quarry limestone area, with well observed opposite pitches north and south of it, forming a shorter and shallower trough in the same axis. The section ends on the east of Savage mountain. The length of the Ragged mountain trough is about 7½ miles, and the entire length of the Farnham's quarry trough, extending beyond the limit of the section, would be about 6 miles

Section Q follows for 14½ miles the axis of the central or Greylock syncline, beginning at the foot of Clarksburg mountain, a little north of Cross-section A. From observations made by other members of this division the quartzite of Clarksburg mountain is known to have a southerly pitch. The lower limestone is, for topographic reasons, supposed to pass completely around between the Clarksburg and Greylock masses, and thus, of course, to conform in pitch to the horizons below and above it. A steep southerly pitch is observed at the north end of the central crest, Mount Williams. This section shows a deep trough corresponding to that on Section P, but with its center about 2 miles farther south, at Cross-section I, in the saddle between Greylock and Saddle Ball. The south end or edge of this trough is at Round rocks, almost in a line with the south end of the great trough in the eastern syncline. This trough is a little longer, measuring 8½ miles. In the incision between Round rocks and Saddle Ball the upper limestone and calcareous schists come to the surface. South of this

[1] North of this part of the syncline, at the south end of Ragged mountain, the vertical distance between the top of the upper limestone horizon, where it is overlaid by the smaller mass of the upper schist, and the lowest contour, where the upper limestone occurs, together with the slight thickness of the deposit necessitate a southerly pitch. Thus also south of the saddle (the Bellows-pipe); and for similar reasons a northerly pitch is supposed between that saddle (Section G) and locality 632 in the Notch (Section F).

is a shallower trough analogous and parallel to the minor one shown on Section P.

Sections R′ and R″ pass through two of the minor synclines on the west flank of the Greylock mass; R′ through Stone hill and Deer hill, the synclinal axis of which probably continues southward through East mountain (Section L) and Potter mountain. At the north end (see Appendix A, Stone hill) the north pitch is not directly observable, but is partially indicated by an observation of Mr. Hobbs in one of the ravines of the Taconic range. The relations between Stone and Deer hills are a repetition of those which have been inferred between Clarksburg mountain and the Greylock mass, the quartzite of Stone hill pitching under the limestone of Green river, and that under the schists of Deer hill.

Section R″ passes through Sugarloaf mountain (see Appendix B), one of the smaller lateral synclinal axes, which, farther north, appear in Bald mountain and Symond's peak (Sections G and I). In this part of the syncline, which measures only about 6 miles in length, there are two well marked troughs, one underlying Sugarloaf, and the other the high schist ridge south of it.

RÉSUMÉ, STRUCTURAL.

Mount Greylock, with its subordinate ridges, is a synclinorium consisting in its broadest portion, of ten or eleven synclines alternating with as many anticlines. While the number of these minor synclines is so considerable at the surface, it is found, in carrying the sections downwards, that they resolve themselves chiefly into two great synclines with several lateral and smaller ones. The larger of these two forms the central ridge of the mass; the smaller one, east of it, forms Ragged mountain and an inner line of foothills farther south. The anticline between these coincides with the Bellowspipe; that on the west of the central syncline is a little west of the north and south part of the Hopper. The major central syncline is so compressed east of Symonds peak (Mount Prospect) and Bald mountain, and its axial plane is so inclined to the east that the calcareous strata, which underlie the central ridge, have on its west side a westerly dip (Sections G and I). Farther south this syncline opens out (Section K), and all the relations become more normal. But between the villages of Cheshire and Lanesboro the folds become sharper again and more compressed, and the schist area rapidly narrows (Sections N and O), and the structure continues much compressed to the extremity of the mass. On either side of these two main synclines the subordinate folds are more or less open, and have their axial planes vertical or else inclined east or west. The continuity of the folds and their mutual relations are shown in Fig. 72. Longitudinal sections along the two main synclinal axes (P and Q) show that the trough bottom deepens at two points. In the eastern syncline (P) the deeper part of the northern trough is shown to be about under the center of Ragged mountain, while in the central one (Q) it is about 2 miles farther south between Greylock and Saddle Ball (Section I); and this also would seem to be the deepest part of the entire synclinorium. The northern edge of both of these troughs is at the extreme north end of the Greylock mass, and their southern edge $7\frac{1}{2}$ to $8\frac{1}{2}$ miles distant, near Round rocks and the southeast spur of Saddle Ball. South of these main troughs are two shallower parallel ones, the centers of which lie west of Cheshire reservoir (P, Q). To the west of these two long axes the mountain mass is made up of

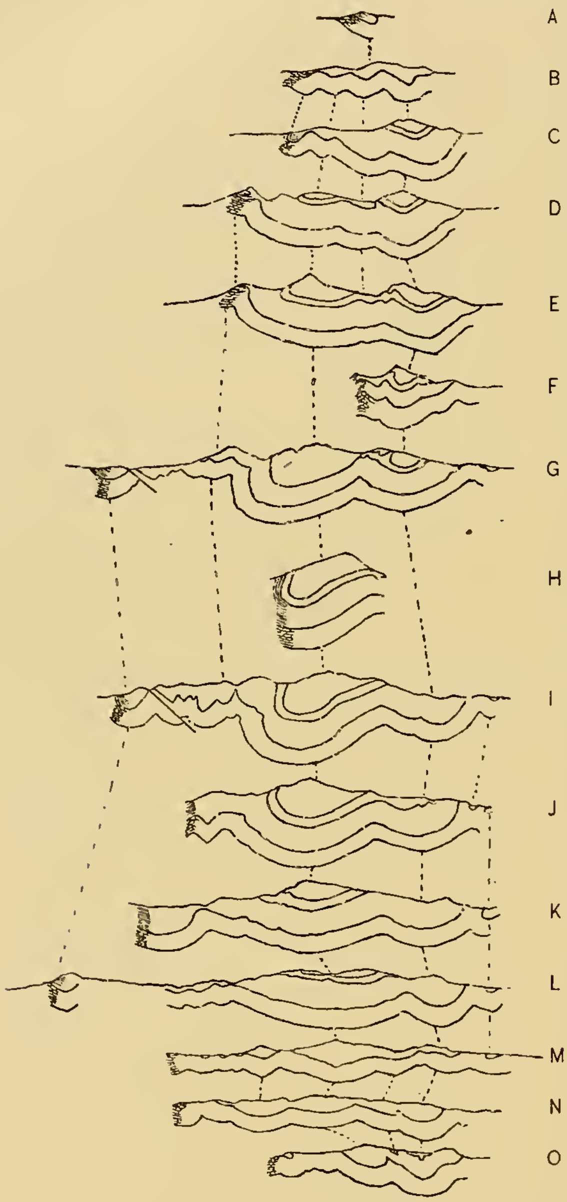

Fig. 72.—Diagram showing the continuity of the main folds in the Greylock synclinorium. Reduced from the large sections, Pls. XVIII–XXII.

numerous minor folds which do not show the continuity seen in P and Q. It will be observed that the direction of these two main synclines represented by P and Q is north-northeast to south-southwest, thus nearly parallel with the direction of the valley lying between the Clarksburg granitoid mass and Hoosac mountain, and that at the south end they converge, and perhaps unite in the narrow schist ridge between Berkshire and Lanesboro villages. Traversing the folds of this canoe-like complex synclinorium is a cleavage-foliation, sometimes microscopically minute, dipping almost uniformly east. This cleavage-foliation is distinct from the "slaty-cleavage" early described by Sedgwick, Sharpe, and Sorby and reproduced experimentally by Tyndall and Jannetaz, but consists sometimes of a minute, abrupt, joint-like fracturing of the stratification laminæ, but more generally of a faulting of these laminæ as the result of their extreme plication—a mode of cleavage "Ausweichungsclivage" (slip cleavage) so well described by Heim and recently reproduced in part by Cadell[1] by a slight modification of the experiments made by Prof. Alphonse Favre, of Geneva, in 1878.[2] This fault-cleavage, when carried to its extreme, results in a form of cleavage very nearly approaching, although not identical with, slaty-cleavage. To the unaided eye all traces of stratification-foliation are lost, and even under the microscope they are so nearly lost as to be of no avail in determining the dip.

LITHOLOGIC STRATIGRAPHY.

As may be inferred from the descriptions of the sections, there are five more or less clearly defined horizons in the Greylock mass. These are described below, beginning with the lowest.

The Vermont formation.—The feldspathic quartzite of the northwest end of Deer hill, which corresponds to the quartzite of Clarksburg and Hoosac mountains and of Stone hill, will be noticed more particularly in Appendix A, on Stone hill. This is Emmons's "Granular Quartz," and has recently been shown to be of Lower Cambrian age.

The Stockbridge limestone.—The crystalline limestone of the Hoosac and Green river valleys, which has long been known to constitute the base of Mount Greylock, is the Stockbridge limestone of Emmons, and extends

[1] Op. cit. (see p. 137), third series of experiments.

[2] Alphonse Favre: The formation of mountains. Nature, vol. 19, 1878, p. 103.

through Berkshire up into Vermont. It has been shown to be of Cambro-Silurian age.

The Berkshire schist.—An overlying mass of schist forms the lower, steeper slopes of the mountains on all sides. This is a part of the magnesian or talcose slate of Emmons, Dana's hydro-mica schist, and has come to be regarded as of Lower Silurian age.

The Bellowspipe limestone.—A series of limestone strata and calcareous (sometimes noncalcareous) schists constitutes the higher benches, the Notch, and the Farnham's Quarry area. In places the rock is quartzite. This horizon seems to have been overlooked by previous geologists on Greylock. In 1888 Mount Everett, near Sheffield, in southern Berkshire county; Mount Anthony, near Bennington, Vermont; Mount Equinox, near Manchester, Vermont, and Mount Dorset (Eolus), near Dorset, Vermont, were visited by the writer in the hope of finding again on some of these higher summits of the Taconic range the upper limestone and calcareous schist of Greylock, but a careful exploration of them all failed to yield any trace of this horizon, excepting on Mount Anthony. A bench of calcareous schist occurs there in the mass of schist above the limestone, but the relations are not sufficiently clear to enable one to determine whether these calcareous layers form part of the Berkshire schist or Bellowspipe limestone formations. During the year 1889, however, quartzites were found on Monument mountain, in southern Berkshire, which appear to overlie the Berkshire schist, and thus seem to belong to the Bellowspipe limestone formation.[1]

The Greylock schist.—A second series of schists similar to the lower ones constitutes all the higher summits of the central ridge and the top of Ragged mountain. This forms part of Emmons's magnesian or Talcose slate and, together with the Berkshire schist, has been regarded by Hall and Walcott as of Hudson River age, and by Dana as representing some member of the Lower Silurian.

All these groups of strata succeed each other conformably.

[1] The theory advanced by Mr. W. H. Hobbs during the printing of this monograph (see Journal of Geology, vol 1, No. 7, Chicago, October-November, 1893, p. 725), that the limestone along the eastern foot of Mount Everett corresponds to the Bellowspipe limestone and the schists which overlie it to the Greylock schist requires verification to accord with results farther north.

PETROGRAPHY.

The petrographic character of the beds of these formations will now be described with the aid of Mr. J. E. Wolff's notes on the microscopic sections, which have been briefly summarized.

THE VERMONT FORMATION.

As the beds of this formation are only represented by one or two outcrops in the Greylock area they will only be described in connection with Stone hill in Appendix A.

THE STOCKBRIDGE LIMESTONE.

The lower limestone is a coarsely or finely crystalline limestone or marble, usually white, but often banded or mottled, and in places entirely dark grey, and there argillaceous. South of and near the South Adams quarries it is very quartzose, and at the south end of Stone hill there are gradual passages from limestone to quartzite, the rock consisting of an "aggregate of calcite grains with rarely a small grain of feldspar and of quartz." About Williamstown and along the Green river north of Sweet's corners, the limestone is very fine grained, and has a hardness intermediate between that of quartzite and limestone, and contains occasional quartz grains. This fine-grained quartzose limestone may be more characteristic of the base of the horizon, but pure quartzite occurs near the top.

The coarse crystalline limestone is often so micaceous as to resemble a gneiss.[1] A specimen from a point a little southeast of the North Adams reservoir was found to consist of "coarse grains of calcite interbanded with muscovite and biotite, and containing occasional porphyritic crystals of feldspar. The feldspars contain inclusions of muscovite, rutile, pyrite, etc. There are occasional grains of quartz. Some fragments of feldspar are microcline, and the calcite cuts across these grains," indicating the possibility of replacement by calcite. The limestone about Sugarloaf mountain is also quite micaceous. Prof. Dewey speaks of the flexibility of this micaceous limestone from New Ashford.[2] Lenses and seams of quartz are not infrequent. Prof. Emmons noticed the occurrence of albite in the limestone of

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[1] See E. Hitchcock. Final Report Geology of Massachusetts, p. 569.

[2] "Notice of the flexible or elastic marble of Berkshire county." Am. Jour. Sci., 1st ser., vol. 9, 1825, p. 241.

Williamstown,[1] also the presence of galena and zinc blende here and there in small quantities.

Prof. E. Hitchcock gave five analyses of the limestone of this horizon, which show it to be in places a dolomite.[2]

In the upper part, near the overlying schist, occur irregular deposits of limonite, as at Cheshire, and along the north side of Mount Prospect, and on the east side of Potter mountain.[3] Prof. Dana has fully explained the origin of these iron-ore beds.[4]

Towards the upper part of the limestone occur also strata of quartzite; thus on the east side of the extreme end of the Greylock schist mass near Pittsfield, and also near the Adams quarries.

The fossils found by Mr. Walcott, and already referred to, came from this horizon, but fossils seem to be exceedingly rare.[5]

The structural peculiarities of the rock are its almost universal flexure into minor pitching folds, and, as already explained (p. 157), its not infrequent minute plications, and also its cleavage sometimes obliterating all trace of stratification.

THE BERKSHIRE SCHIST.

This consists of the lower sericite-schists. The groundmass of these schists is made up of interlacing fibers of muscovite (sericite) and folia

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[1] Geology Second District, New York, 1842, p. 158.

[2] Final Report Geology of Massachusetts, 1841, p. 80, 81.

[3] At the latter place (Lanesboro Iron company's ore bed) the ore occurs in two positions. In one place, owing to an overturn, it lies below the limestone and above the schist. In another it lies on the upper side of a small limestone anticline, the schist capping having been eroded. In another place a reddish, partially decomposed schist overlies the limestone, the ore probably occurring between. The stratigraphic position of the ore is identical in all these cases, however. On the schist side of the ore there is usually a mass of mottled clay, probably originating in the decomposition of the schist, and on the limestone side a yellowish ochre. Manganese ore (pyrolusite) occurs here associated with the iron ore (limonite).

[4] Am. Jour. Sci., 3d ser., vol. 14, 1877, p. 132.

Berkshire geology in "Four papers of the Berkshire Historical and Scientific Society," published by the society, Pittsfield, June 1, 1886, p. 19.

Much of interest in reference to these Silurian limonites will be found also in vol. 15 of the Tenth Census (1880), Washington, 1886, especially in the introductory chapter by Prof. Raphael Pumpelly on the geographical and geological distribution of the iron ores of the United States (p. 10, on the limonites), and also in Mr. Bayard T. Putnam's notes on the samples of iron ore collected in Connecticut and Massachusetts, p. 87.

[5] Since the completion of the manuscript the writer has found crinoid stems in the upper part of the limestone on Quarry hill, New Ashford.

of chlorite and grains of quartz. Whether the hydrous character of the rock proceeds from the chlorite or from some other hydrous mica can hardly be determined, as the two minerals are intimately interlaced. The talcose appearance and touch of much of the Greylock schist, which have given it the names of talcoid-schist, hydro-mica schist, magnesian slate, is due largely to the presence, almost if not quite universal, of these exceedingly minute folia of chlorite;[1] and the variable proportions of the chlorite and the muscovite in different localities explain the difference in the chemical analyses of it as well as the variety of names geologists have given it. The color of these schists varies with the varying proportions of its principal ingredients—muscovite, chlorite, and quartz. Often it is black from the presence of graphite, or porphyritic from the presence of feldspar, or spangled from the presence of other minerals. Quartz lenses and seams are almost universal. There are also great variations in the texture of these rocks. Their structural peculiarities have been described at length on pages 138–157, and constitute one of their chief characteristics

The following is a brief summary of Mr. Wolff's microscopic analyses of the typical specimens collected: Among the minerals of most frequent occurrence are black tabular rhomboidal crystals or lenticular plates of ilmenite and chlorite, a plate of ilmenite being interleaved between two of chlorite. "Similar forms have been described by Renard from the metamorphic rocks of the Ardennes, but they are surrounded by sericite layers and not by those of chlorite." He also describes large plates of chlorite inclosing small octahedra of magnetite, which also occur on Greylock.[2] Very minute bluish green crystals resembling the ottrelite of the Rhode Island Coal-measures are found.[3]

Perhaps fully as common, if not more so, is albite, which occurs in simple twins or untwinned, sometimes with a rim of clear feldspar separated or not from the central crystal by a rim of quartz, and surrounded by fibers of muscovite and chlorite. (Thus specimens from locality 458, south

[1] See E. Hitchcock, Report Geol. of Vermont, 1861, vol. 1, p. 504. James D. Dana, Am. Jour. Sci., 3d ser., vol. 4, p. 366, and vol. 14, p. 139.

[2] See A. Renard, Recherches sur la composition et la structure des phyllades ardennais. Bulletin Mus. Roy. Belg., vol. 2, 1883, p. 127–152, and vol. 3, 1885, p. 230–268.

[3] See J. E. Wolff: On some occurrences of ottrelite and ilmenite schist in New England. Bull. Mus. Comp. Zool., Geological Series, vol. 2, p. 159, 1890. Cambridge, Mass.

of Sugarloaf mountain; 494, between that mountain and Round rocks; 324, on the line of contact between the Stockbridge limestone and the small mass of the Berkshire schist south of Sugarloaf; 474, in the deep cut between east and Potter mountains; 475, at the southwest end and foot of East mountain in Hancock; and 703, at the triangulation point on the north summit of East mountain.

More rarely garnets occur, giving rising to chlorite. Thus at locality 40, on the tongue of schist north of the Adams quarries. Garnets occur also in the small isolated schist mass west of Lanesboro village.

The graphitic schist of this horizon was early noticed by Emmons[1] and Hitchcock.[2] It generally occurs near the underlying limestone, as about New Ashford, at locality 274, and near Maple Grove station, locality 139, on the east side of Greylock. The graphite is in microscopic, irregular layers, or in masses, surrounded by even sized quartz grains and scales of graphite and muscovite.

Octahedral crystals of magnetite are in many places scattered through the schist,[3] but the most characteristic minerals are albite, interleaved ilmenite and chlorite, and graphite.

The rock is sometimes calcareous, but not continuously so. Rarely veins of calcite and chlorite traverse it. Between New Ashford and Lanesboro a graphitic limestone occurs in the schist, containing angular, often rhombohedral, crystals of albite partially replaced by calcite.

THE BELLOWSPIPE LIMESTONE.

For structural reasons the Farnham's quarry limestone has been placed here. That limestone is generally white (though sometimes gray) and highly crystalline, like the Stockbridge limestone; but in the other areas of this formation the limestone is finer grained, less often white, frequently argillaceous, micaceous, or pyritiferous. Frequently the micaceous element predominates and the rock is a calcareous schist, and in several localities the calcareous element disappears altogether. Galena, zinc blende, and siderite occur along with pyrite in the limestone of the Bellowspipe. Associated with these limestone and calcareous schists are beds of slightly micaceous

[1] Geology of Second District, New York, p. 153.

[2] Final Report on the Geology of Massachusetts, p. 581.

[3] Emmons, Geol. Second District, New York, p. 141.

granulite or fine grained gneiss. These do not seem to be confined to any particular portion of the horizon, nor are they persistent where they do occur.

The seams and lenses of quartz in the calcareous schist are calcareous, and the rock itself is often calcareous where it looks least so, and vice versa. In structure it shows the same peculiarities as the limestone and schist of the lower horizons.

No fossils have yet been found in this formation on Greylock, although the rock in many places is sufficiently fine grained and not too metamorphic for their preservation.

The only reason for the entire omission of this horizon from Emmons's section seems to be that his section traversed the mountain in one of the few places where there are no outcrops on the calcareous belts.[1]

The following is a summary of Mr. Wolff's report on these rocks. A bluish gray, finely crystalline limestone composed of calcite grains and quartz grains, with occasional flakes of muscovite and considerable pyrite scattered through the calcite.[2] (Thus a specimen from locality 212 on Peck's brook, about 2 miles south of the Bellowspipe.) Traversing the limestone are thin beds of graphitic, pyritiferous quartzite composed of quartz, feldspar, pyrite, graphite, and muscovite. (Thus locality 704 in the Notch about three-quarters of a mile south of its highest point.)

The calcareous schist is composed of large grains of calcite mixed with stringers of muscovite and graphite containing inclusions of mica, graphite, calcite, and quartz. Pyrite and small fragments of microcline also occur in it. (Thus a specimen from locality 712 on the west side of Ragged mountain near its south end.)

The feldspathic quartzite so often associated with or replacing the calcareous schist of this horizon consists of an interlocking aggregate of grains of quartz and feldspar with rare flakes of muscovite, small crystals of rutile, and specks of limonite (thus at locality 345 in the Notch, west of the center of Ragged mountain); and the gneiss, which seems intimately related to the above, is a mixture of quartz with a large amount of feldspar, twinned and untwinned plagioclase, with occasional grains of microcline and muscovite

[1] See Emmons's American Geology, part 2, p. 18. "From the termination of the limestone [i. e., the Stockbridge limestone] to the top of Greylock the talcose slate is uninterrupted."

[2] Recent assays of a similar specimen of this horizon are said to have shown the pyrite to be auriferous, but not sufficiently so to give the rock any metallurgical value.

plates, magnetite, zircon, rutile, etc. (Thus at locality 616, in the gneiss area west of King Cole mountain and Maple Grove station.)

THE GREYLOCK SCHIST.

This also consists of schists resembling in their petrographic character, appearance, and structure those of the Berkshire schist formation. If there be any difference between them it consists in that the upper schists are more chloritic and albitic, and less frequently calcareous or plumbaginous than the lower ones, but all the minerals occurring in the Berkshire schist recur in the Greylock schist.

The interleaved plates of ilmenite and chlorite are the same as in the Berkshire schist. (Thus specimens from locality 1,076 in the most southerly of the Hopper ravines, about 1,300 feet below Greylock summit.)

The magnetite octahedra are also frequently met. (Thus at locality 449 in the cliffs on the south side of Saddle Ball, and again west of the top of Greylock about a quarter of a mile east of locality 1,076.)

The feldspathic schists of this formation are characterized here and there by large crystals of albite. At locality 709, on the west side of the Notch, east of Mount Fitch near section F, the rock might be called an albite-gneiss. It consists of "numerous squarish albite crystals, rarely in simple twins, crowded closely together," but surrounded by "interlacing fibers of muscovite, chlorite, and biotite with magnetite grains and many tourmaline needles. Quartz occurs rarely, in little grains or aggregates. The biotite and chlorite are often in separate masses, but often pass into one another in the same piece. Some of the chlorite may result from the hydration of biotite. The feldspars contain inclusions of muscovite, chlorite, biotite, magnetite, tourmaline, etc." Mr. Wolff separated the feldspar of this rock by the use of the Thoulet solution, and a double analysis of it was made at the chemical laboratory of the U. S. Geological Survey in Washington by Mr. R. B. Riggs (F. W. Clarke, chief chemist). The result shows the feldspar to be an almost pure albite.

Analysis No. 567. Feldspar from specimen 709a, D. I. 1886.

	I.	II.
SiO_2	68.08	67.83
$Al_2O_3+(Fe_2O_3<5\%)$	20.11	19.92
MnO	trace	trace
CaO	trace	trace
MgO	?	?
Na_2O	11.00	11.65
K_2O	.36	.25
Ignition	.31	.12
	99.86	99.77

Dried at 105 C. Specific gravity slightly above 2.6545, between 2.6545 and 2.61.[1]

At the south end of the top of Ragged mountain in the small isolated schist area (locality 764), the albite gneiss is "coarsely foliated with a wavy structure composed of bands of dark mica, alternating with irregular layers of calcite mixed with quartz and large rounded feldspar crystals. Needles of tourmaline occur occasionally. The albite crystals are not twinned, have a rounded outline, often lie with their longer axes across the foliation of the rock, and contain inclusions of calcite, quartz grains, and flakes of both micas. The groundmass consists of interlacing fibrous layers of muscovite and biotite, little grains of quartz and great quantities of calcite, not in grains but in masses. The calcite sometimes penetrates a large feldspar, breaking it up into isolated cores of feldspar, surrounded by calcite. It is difficult to say with certainty whether the calcite was formed later than the quartz and mica or contemporaneously with them. It occurs in vein-like masses, not in grains; when it has encroached on the feldspar it does so irregularly and not parallel to the schistosity of the rock, as the quartz and mica do; rarely tongues of calcite cut in two inclusions of quartz in the feldspars—it seems rather therefore to be pseudomorphous—replacing quartz as well as feldspar."

Towards the top of Greylock and along the central ridge the feldspar crystals are very minute and are not rounded. (Thus at locality 861 on the Greylock road.)

[1] Mr. Wolff adds for comparison the analysis of a colorless albite from Kiräbinsk, Urals. SiO_2 68.45, Al_2O_3 18.71, FeO 0.27, NaO_2 11.24, K_2O 0.65, CaO 0.50, MgO 0.18. Total 100. Spec. grav. 2.624.

Fig. 73 represents a slightly enlarged section of a specimen of the feldspathic schists, which may be regarded as petrographically and structurally typical of this formation.

From all the foregoing the transitional lithologic character of the formations is manifest.[1] In the Stockbridge limestone there are passages from limestone to quartzite and to schist. In the Berkshire schist the rock is often calcareous. In the Bellowspipe limestone there are transitions from limestone to calcareous schist, and from these to noncalcareous schists and to quartzite and gneiss. Mr. Wolff's microscopic examinations indicate that this feature is due in part to various replacements and other

FIG. 73.—Thin section of albitic sericite-schist from locality 542, between Greylock summit and Saddle Ball, enlarged 1½ diameters. A typical specimen of the Greylock schist, showing the minute plications, the quartz laminæ, the slip cleavage with the albite interspersed. (From a photograph.)

chemical changes at the time of or subsequent to metamorphism, as well as in part to variations in the character of the original sediments.

THICKNESS.

The numerous folds, and the fact that they are sometimes compressed and overturned, not to mention the difficulties arising from cleavage, render exact measurements of thickness very difficult, if not impossible, in the Greylock area, but approximations can be obtained. The figures appended to the following table are given only as estimates based upon the sections. The difference in the estimates arises in part from the varying amount of thickening in plication (Staunng). As thickening in consequence of plica-

[1] Prof. J D. Dana refers to this in several of his papers on the Taconic rocks.

tion generally occurs in the Greylock mass the actual thickness is probably less than the minimum figures given in the table, and may possibly be considerably less. It will be observed, however, that the maximum thickness of the entire series does not exceed the minimum thickness attributed to the Lower Silurian rocks in the Appalachian region.[1]

GEOLOGIC AGE.

The question of the age of the beds of Greylock, and the treatment of the whole subject from the standpoint of historic geology are beyond the province of this report, but the various conclusions which have been reached and are being reached in regard to the geologic age of these formations are added in separate columns for convenience of reference.

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[1] See J. D. Dana, Manual of Geology, third edition, pp. 192, 210.

RÉSUMÉ, LITHOLOGIC STRATIGRAPHY.

The general lithologic character, order, and estimated thickness of the strata of Mount Greylock, East mountain, and Stone hill.

Formations, natural order.	Lithologic character.	Thickness.	Age.[1]			
			Emmons, 1855.	Hall, 1839–1844.	Dana, 1882–1887.	Walcott, 1888.
		Feet.				
Greylock schist. Sg.	Muscovite (sericite), chlorite, and quartz schist, with or without biotite, albite, magnetite, tabular crystals or lenticular plates of interleaved ilmenite and chlorite, ottrelite, microscopic rutile and tourmaline. These schists are rarely calcareous or graphitic.	1,500–2,200	Pre-Potsdam. Lower Taconic No. 3. "Talcose or magnesian slate."	TRENTON. (Hudson river.)	LOWER SILURIAN.	TRENTON. (Hudson river.)
Bellowspipe limestone. Sbp.	Limestone, more or less crystalline, generally micaceous or pyritiferous, passing into a calcareous schist, or a feldspathic quartzite, or a fine-grained gneiss with zircon and microcline, or a schist like Sb. The more common minerals are: Graphite, pyrite, albite, and microscopic rutile and tourmaline. More rare: Galena, zinc blende, siderite.	600–700	Pre-Potsdam. Lower Taconic No. 3. Included in "Talcose or magnesian slate."	TRENTON. (Hudson river.)	LOWER SILURIAN.	TRENTON. (Hudson river.)
Berkshire schist. Sb.	Muscovite (sericite), chlorite, and quartz schist, with or without biotite, albite, graphite, magnetite; frequently with tabular crystals or lenticular plates of interleaved ilmenite and chlorite. Garnet, ottrelite. Microscopic rutile and tourmaline. These schists are in places calcareous, especially towards the underlying limestone, where they are often graphitic.	1,000–2,000	Pre-Potsdam. Lower Taconic No. 3. "Talcose or magnesian slate."	TRENTON. (Hudson river.)	LOWER SILURIAN.	TRENTON. (Hudson river.)
Stockbridge limestone. ЄSs.	Limestone, crystalline, coarse or fine; in places a dolomite, sometimes quartzose, or micaceous, more rarely feldspathic, very rarely fossiliferous. Galena and zinc blende rare. Irregular masses of iron ore (limonite) associated sometimes with siderite, often with manganese ore (pyrolusite). Some quartzite.	1,200–1,400	Pre-Potsdam. Lower Taconic No. 2. "Stockbridge limestone."	LOWER SILURIAN. (Trenton and lower.)	LOWER SILURIAN.	TRENTON. (Trenton.) CANADIAN. (Chazy, Califerous.)
Vermont formation. Єv.	Quartzite, fine grained, alternating with a thin-bedded, micaceous, and feldspathic quartzite. (The latter with calcite, pyrite, tourmaline.) Associated with these quartzites, and probably at the base of this horizon, is a coarse-grained micaceous quartzite (tourmaline) passing, in places, into a conglomerate, and containing blue quartz, feldspar (plagioclase, microcline) and zircon, all of clastic origin.	800–900	Pre-Potsdam. Lower Taconic No. 1. "Granular quartz."		CAMBRIAN. (Potsdam.)	LOWER CAMBRIAN. (Olenellus.)
	Total thickness: Minimum	5,000				
	Maximum	7,200				

[1] For Prof. E. Emmons's views see his works already referred to, especially his American Geology, Part 2, pp. 10–18, 48, 128.

For Prof. James Hall's views, announced as early as 1839–1844, but not then published, see American Journal of Science, 3d ser., vol. 28, October, 1884, p. 311: "Prof. James Hall on the Hudson river age of the Taconic slates." Also Jules Marcou: "On two plates of stratigraphical sections of Taconic ranges by Prof. James Hall," Science, vol. 7, 1886, p. 393, New York.

For Prof. Dana's views see his papers: "Geological Age of the Taconic System," Quarterly Journal of the Geological Society of London, vol. 38, 1882, p. 397; "On Taconic Rocks and Stratigraphy," American Journal of Science, 3d ser., vol. 33, May, 1887, p. 410, and also "On the Hudson river Age of the Taconic Schists," etc., ibid, vol 17, 1879, p. 375.

For Mr. Charles D. Walcott's views see the map and section appended to his paper, "The Taconic system of Emmons, and the use of the name Taconic in geologic nomenclature," American Journal of Science, 3d ser., vol. 25, April, May, 1888, pp. 307, 394, pl. 3, also "The Stratigraphical succession of the Cambrian Faunas in North America" (abstract of his

AREAL AND STRUCTURAL.

The geologic map of the Greylock, East and Potter mountain masses, presents a great body of the schists of the Berkshire schist formation, surrounded by the underlying Stockbridge limestone. It is probable, although not demonstrable, that this limestone passes around the north end of the Greylock mass, between the schist on the south and the quartzite (Vermont formation) of Clarksburg mountain on the north. It is also probable that that quartzite underlies the entire Greylock synclinorium, for it occurs on the north on Clarksburg mountain, on the east on Hoosac mountain, and on the west on Stone hill, and is also brought up again by a fault on the east side of Deer hill.

The Berkshire schist sends out tongues corresponding structurally to synclines into the lower limestone area, as west of Zylonite on the east side of the range, and at Deer hill on the west side; also at Constitution hill, west of Lanesboro. There are also reentering angles of limestone in the schist area, corresponding to anticlines, as north of Lanesboro, and about New Ashford.

There are isolated schist areas, generally lenticular in form, corresponding to more or less open synclines, as a little southwest of South Adams, and south of Constitution hill, in Lanesboro and about New Ashford. The most interesting of these is Sugarloaf mountain, which is a canoe-shaped open syncline. (See Fig. 74, Appendix B, and Sections M, R.″)

There are also isolated limestone areas, corresponding to compressed anticlines, projecting through the overlying schists, exposed by their erosion. Two of these occur between New Ashford and Lanesboro, and a smaller one is described in Appendix B, at Quarry hill, New Ashford. (Figs.

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remarks before the International Geological Congress, London, September, 1888), in Nature, vol. 38, No. 23, October 4, 1888, p. 551; also his paper, "Stratigraphic Position of the Olenellus Fauna in North America and Europe," American Journal of Science. 3d ser., vol. 37, May, 1889, p. 374.

For a defense of Emmons's classification see "Palæontologic aod Stratigraphic Principles of the adversaries of the Taconic," by Jules Marcou, American Geologist, July, 1888; and for Mr. Marcou's own classification of the Taconic rocks see his memoir, "The Taconic system and its position in stratigraphic geology," Proceedings of the American Academy of Arts and Sciences, vol. 12. Cambridge, 1885, p. 174.

For a summary of the different phases of opinion in regard to the age of the Taconic rocks see "A brief history of Taconic ideas," by J. D. Dana, Am. Jour. Sci., 3d ser., vol, 36, December, 1888, p. 40.

For the literature and a systematic presentation of the Taconic question see Bulletin 81, U. S. Geol. Survey, Correlation Papers—Cambrian, by Chas. D. Walcott. For evidence of the Lower Cambrian age of the lower part of the Stockbridge limestone, see article by J. E. Wolff, "On the Lower Cambrian age of the Stockbridge limestone," Bull. Geol. Soc. Am., vol. 2, 1890, p. 331. Also paper by T. Nelson Dale, "On the structure and age of the Stockbridge limestone in the Vermont valley," Bull. Geol. Soc. Am., vol. 3, 1891, p. 514.

78, 79.) The limestone area in the western part of the Bald mountain spur is anticlinal in structure, but faulted.

The relations which have been described above as existing between the lower limestone (Stockbridge limestone) and the lower schist (Berkshire schist) are repeated at a higher level between the upper limestone (Bellowspipe limestone) and the upper schist (Greylock schist). Ragged mountain and the higher portions of the central ridge (Saddle Ball, Greylock, Fitch, Williams) are synclinoria of the upper schist resting upon and surrounded by the upper limestone. The tongues and reentering angles and isolated schist areas occur here, as well as in the lower formations. But the isolated limestone area southwest of Cheshire, instead of being an anticline of the Stockbridge limestone projecting through the Berkshire schist, seems to be a syncline of the Bellowspipe limestone resting upon the Berkshire schist, homologous to that which encircles and underlies Ragged mountain, but without any similar mass of schist on it. The relative height of the surface of the Farnham's quarry limestone, as shown in Section P, accords well with this interpretation.[1]

RELATIONS OF GEOLOGY TO TOPOGRAPHY.

It remains now to show the relations of the structural, lithologic, and areal geology to the surface features. We find here evidence of the operation of several causes:

First. The mineralogic character of the rock, presenting minerals more or less easily disintegrated by physical or chemical agencies.

Second. The internal structure and position of the strata, forming elevations and depressions in the mass and determining the surface relations of the different kinds of rocks.

Third. Erosion, glacial, as well as pre-glacial and post-glacial, bringing physical and chemical agencies to bear upon those irregularities in the form and composition of the surface.

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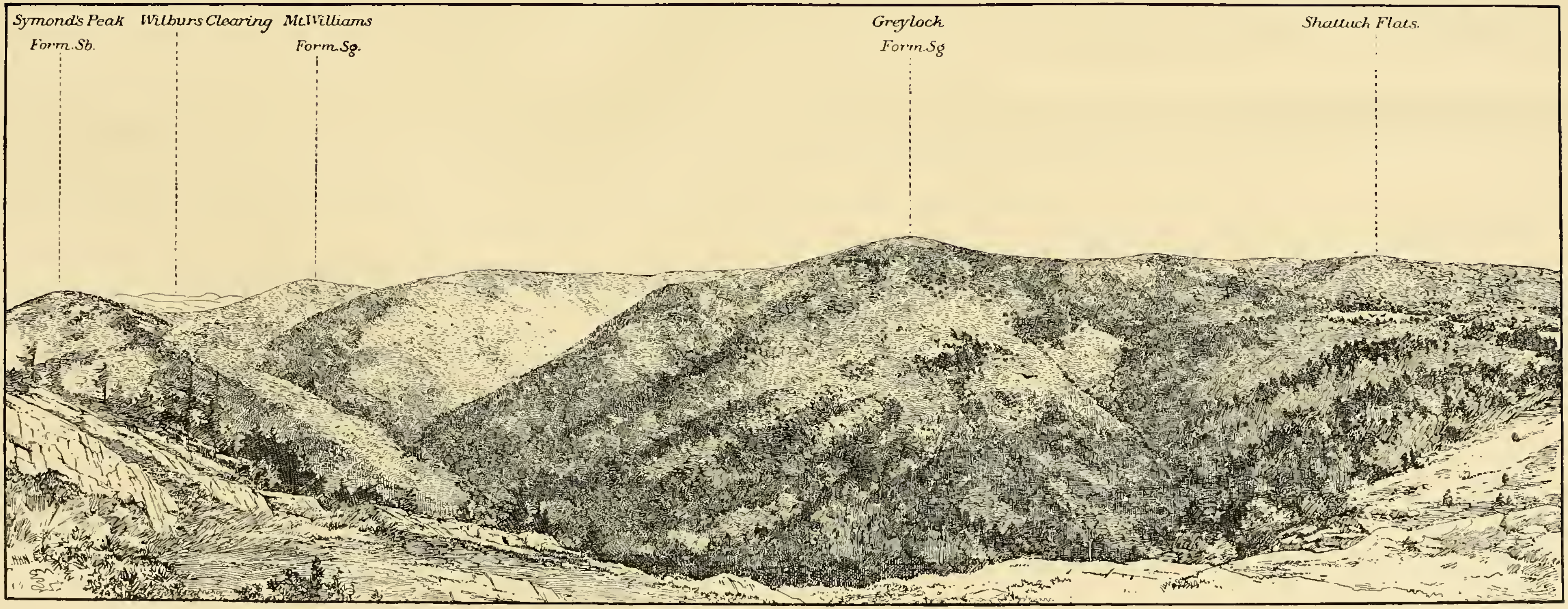
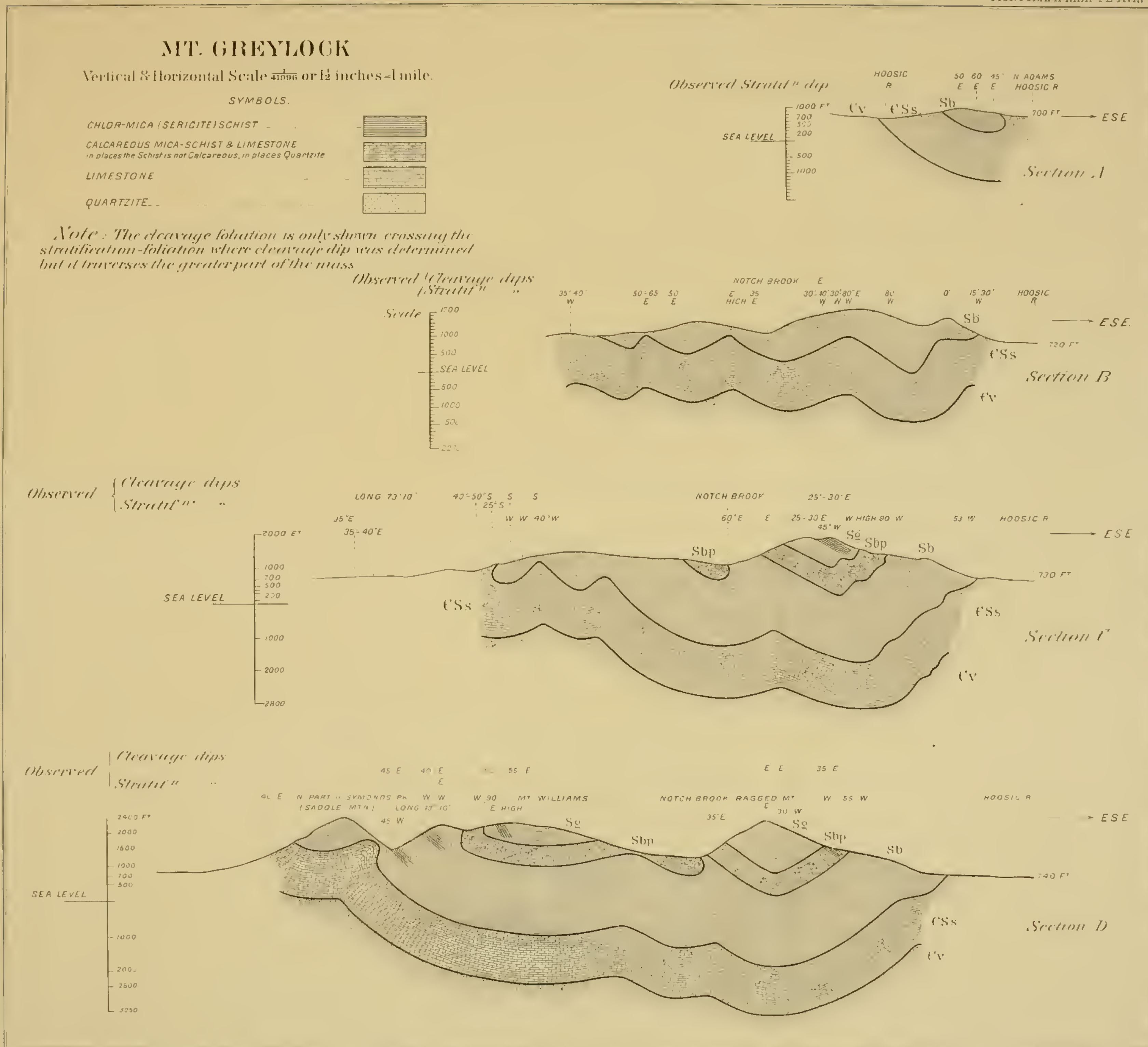
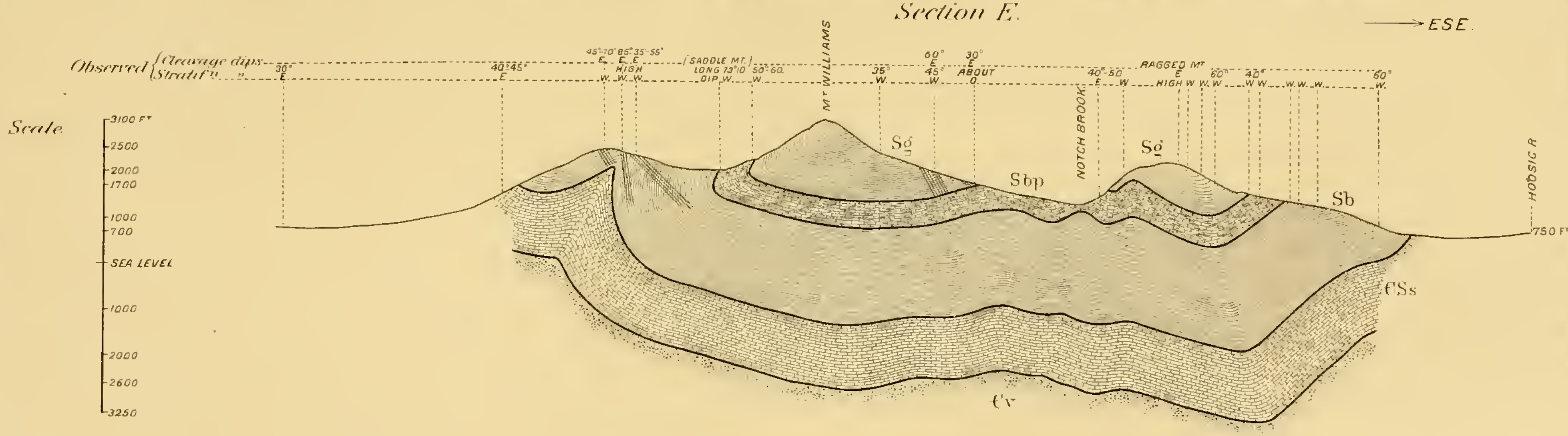
[1] These facts are brought out on the accompanying map and the sections (Pls. I, XVIII-XXIII). Besides the usual dip and strike symbols there have been added on the map symbols indicating the direction and angle of pitch, and also the symbols proposed by Dr. H. Reusch (op. cit.) to indicate the cleavage dip and strike, and finally, numbers of the important localities referred to in this report.

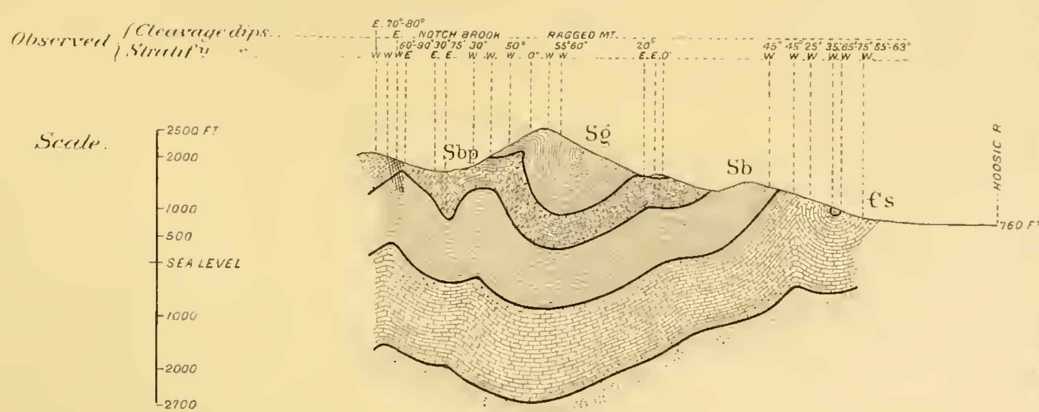


THE NORTH-SOUTH PART OF THE HOPPER.

Seen from the bluffs on Bald mountain (length, 2½ miles), illustrating erosion in the schist area of the Taconic region. This part of the Hopper corresponds to an anticline in the Berkshire schist (Sb) and to the Bellowspipe limestone, Sbp. The Saddle (Wilbur's clearing) on the left, between the Greylock schist (Sg) of the central crest on the east and the Berkshire schist of Symonds Peak (Mount Prospect) on the west, and the corresponding high pasture on the right (Shattuck flats, 2 birds) are uneroded portions of the bench made up of the Bellowspipe formation (Sbp), here however a calcareous schist. In the foreground, on the extreme left, are ledges of the Berkshire schist with a high southeast dip. From photographs.


MT. GREYLOCK
Vertical & Horizontal Scale or 1½ inches = 1 mile.
SYMBOLS.
CHLOR-MICA (SERICITE) SCHIST
CALCAREOUS MICA-SCHIST & LIMESTONE
in places the Schist is not Calcareous, in places Quartzite
LIMESTONE
QUARTZITE
Note: The cleavage foliation is only shown crossing the stratification-foliation where cleavage dip was determined but it traverses the greater part of the mass
Observed Stratif" dip
HOOSIC R
N ADAMS
HOOSIC R
SEA LEVEL
Section A
Observed Cleavage dips
Stratif"
Scale
NOTCH BROOK
HOOSIC R
ESE
Section B
Observed Cleavage dips
Stratif"
LONG 73°10'
NOTCH BROOK
HOOSIC R
SEA LEVEL
ESE
Section C
Observed Cleavage dips
Stratif"
N PART of SYMONDS PK
(SADDLE MTN)
LONG 73°10'
MT WILLIAMS
NOTCH BROOK
RAGGED MT
HOOSIC R
SEA LEVEL
ESE
Section D





MT. GREYLOCK

Vertical & Horizontal Scale $\frac{1}{41996}$ or $1\frac{1}{2}$ inches = 1 mile.

SYMBOLS

CHLOR-MICA (SERICITE) SCHIST

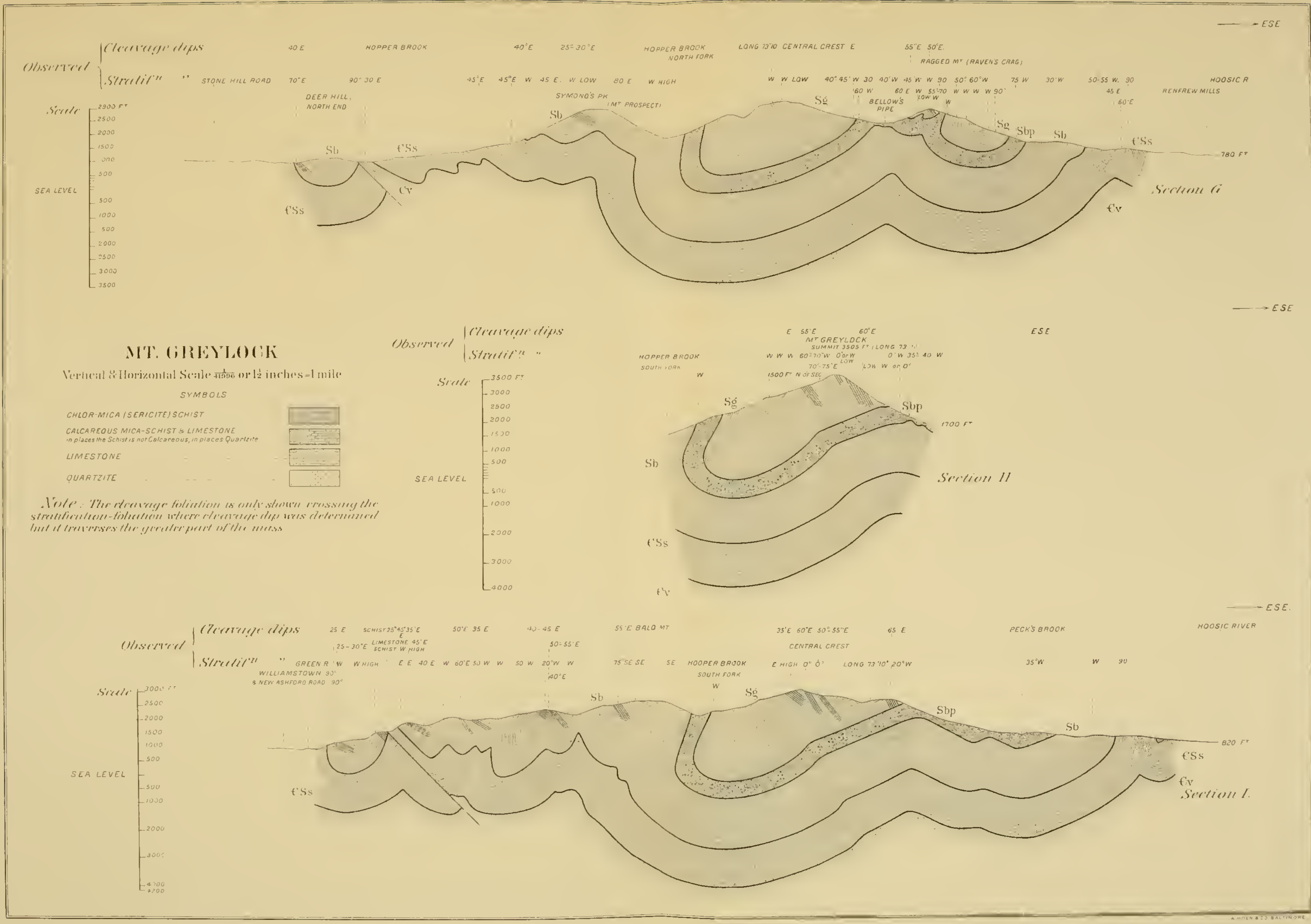
CALCAREOUS MICA-SCHIST & LIMESTONE
in places the Schist is not Calcareous, in places Quartzite.

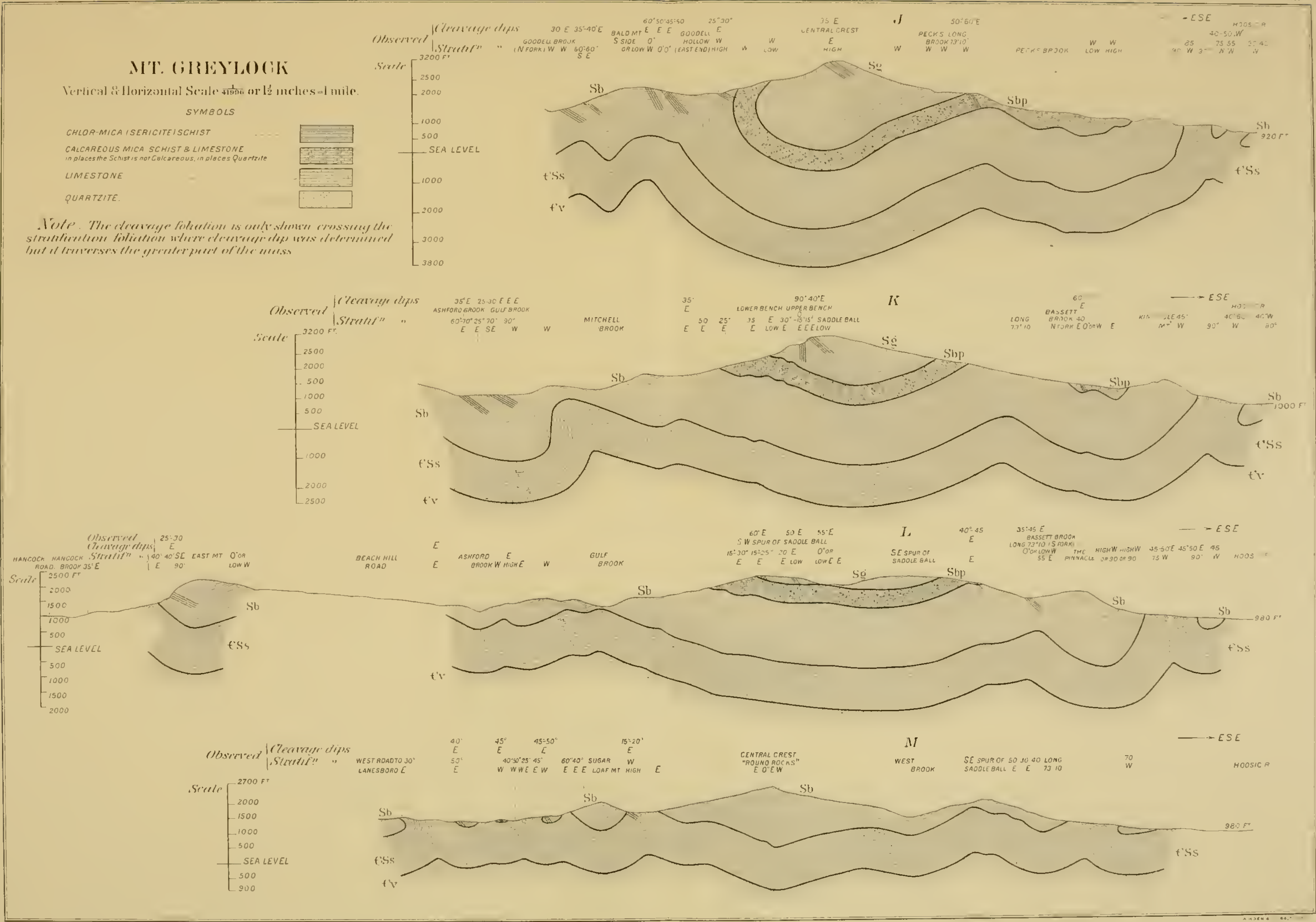
LIMESTONE

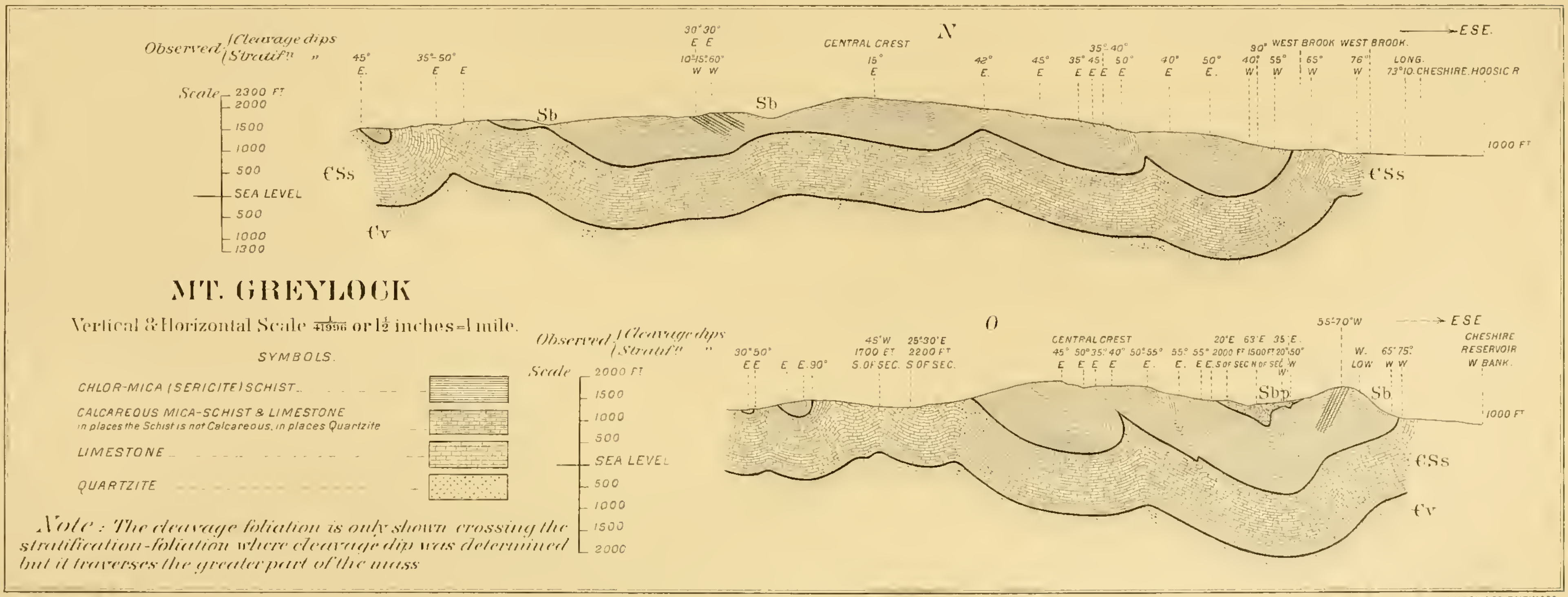
QUARTZITE

Note: The cleavage foliation is only shown crossing the stratification-foliation where cleavage dip was determined but it traverses the greater part of the mass

A. HOEN & CO. BALTIMORE.


MT. GREYLOCK
Vertical & Horizontal Scale 1/31500 or 1½ inches = 1 mile
SYMBOLS
CHLOR-MICA (SERICITE) SCHIST
CALCAREOUS MICA-SCHIST & LIMESTONE
in places the Schist is not Calcareous, in places Quartzite
LIMESTONE
QUARTZITE
Note: The cleavage foliation is only shown crossing the stratification-foliation where cleavage dip was determined but it traverses the greater part of the mass
Observed Cleavage dips
Observed Stratif.n
Scale
SEA LEVEL
ESE
Section G
Section H
Section I
HOPPER BROOK
STONE HILL ROAD
DEER HILL, NORTH END
SYMOND'S PK (MT PROSPECT)
CENTRAL CREST
RAGGED MT (RAVENS CRAG)
BELLOW'S PIPE
HOOSIC R
RENFREW MILLS
MT GREYLOCK
HOPPER BROOK SOUTH FORK
GREEN R
WILLIAMSTOWN
BALD MT
PECK'S BROOK
HOOSIC RIVER
780 FT
1700 FT
820 FT
Sb
Sg
Sbp
€Ss
€v


MT. GREYLOCK
Vertical & Horizontal Scale 1/41666 or 1½ inches = 1 mile.
SYMBOLS
CHLOR-MICA (SERICITE) SCHIST
CALCAREOUS MICA SCHIST & LIMESTONE
in places the Schist is not Calcareous, in places Quartzite
LIMESTONE
QUARTZITE.
Note. The cleavage foliation is only shown crossing the stratification foliation where cleavage dip was determined but it traverses the greater part of the mass
J
K
L
M
Observed
Cleavage dips
Stratif"
Scale
SEA LEVEL
ESE
Sb
Sg
Sbp
€Ss
€v

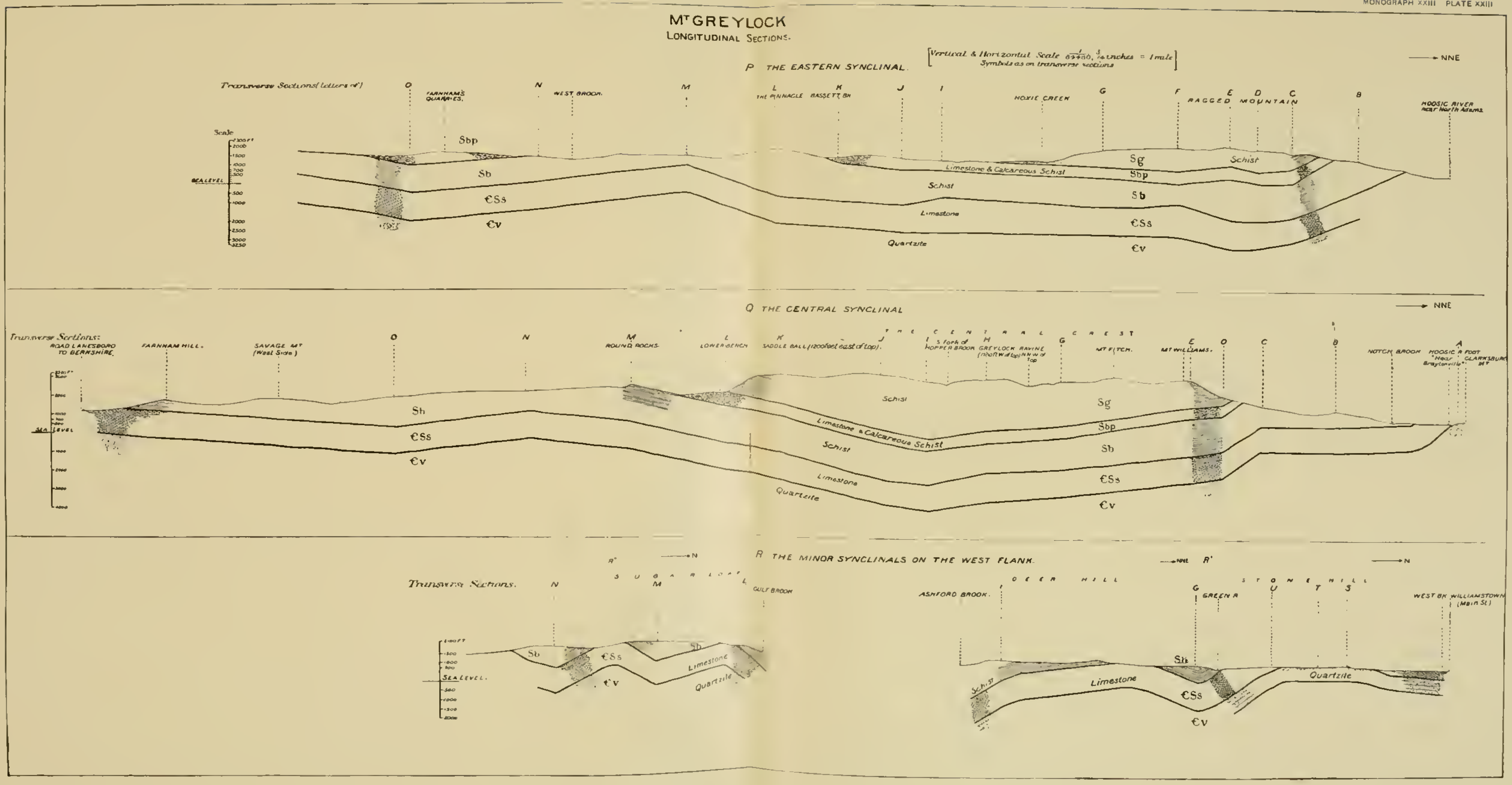


MT. GREYLOCK

Vertical & Horizontal Scale $\frac{1}{41996}$ or $1\frac{1}{2}$ inches = 1 mile.

Note: The cleavage foliation is only shown crossing the stratification-foliation where cleavage dip was determined but it traverses the greater part of the mass

A. HOEN & CO. BALTIMORE



GREYLOCK LONGITUDINAL SECTIONS, P. Q. R.

The interaction of all these have molded the mountain and given it its varied topography.

The physically and chemically more resistant schists form the more elevated portions; also the steeper and more rugged and wooded slopes, while the broad, cultivated valleys of the Hoosic, Green, and Housatonic rivers, and the more gently undulating portions of the mountain generally correspond to limestone areas. The upper limestone strata and calcareous schists constitute the benches of agricultural and pasture land, which form so marked a feature in the Greylock landscape, and to which attention was directed in the Introduction. Thus the Notch and the agricultural character of its surface find their explanation partly in its anticlinal structure and partly in the calcareous element of its strata. The character of the bench on the east flank of Ragged mountain has already been noticed. Similarly the broad bench, which extends for 2 miles at an altitude of 2,000 to 2,500 feet above sea level on the west side of the central ridge between Greylock and Saddle Ball and around "Jones's Nose" (see Pls. XIII, XIV), corresponds to the gently inclined strata of Formation Sbp, with its easily weathering and subsoil-forming micaceous limestone. This accounts for the farms which once dotted its surface, still mostly recognizable as open pasture land. Thus, also, is explained the incision between Round rocks and Saddle Ball. (Fig. 74 and Section Q.)

The 2½-mile long north to south extension of the great Hopper cut was partly occasioned by the trend of the folds and partly by the upturned edges of the calcareous belt, which, on the north, at "Wilbur's pasture," and, on the south, at "Shattuck's flats," still retain something of their former surface outline. (See Pl. XVII.) Prof. Dana's surmise that the north to south Hopper depression is due to a subordinate anticline[1] is correct, but the anticline seems to occur on the west side of the Hopper. The main east to west Hopper incision does not seem to correspond to any structural feature, but to be simply the result of the surface drainage of the west slope of the range eating back, i. e., eastward, through the subordinate folds until it reached the calcareous belt, and then, owing possibly in part to the sharpness and consequent weakness of the anticline west of it, but mainly to the more assailable

[1] On the quartzite, limestone, etc., in the vicinity of Great Barrington, Massachusetts, p. 273.

character of the calcareous belt, and its general trend, erosion proceeded quite as rapidly laterally, north and south, along the strike as easterly across it.

The deep incisions south of the Bald mountain spur (Goodell brook, Mitchell brook, etc.) and the corresponding ravines on the east slope of the range (Peck's brook, Bassett's brook, etc.) are the usual effects of the drainage of a mountain range; and the alternation of precipice and gentle declivity in these ravines is explained by differences in the character of the noncalcareous schists themselves, and also by the alternation of calcareous and

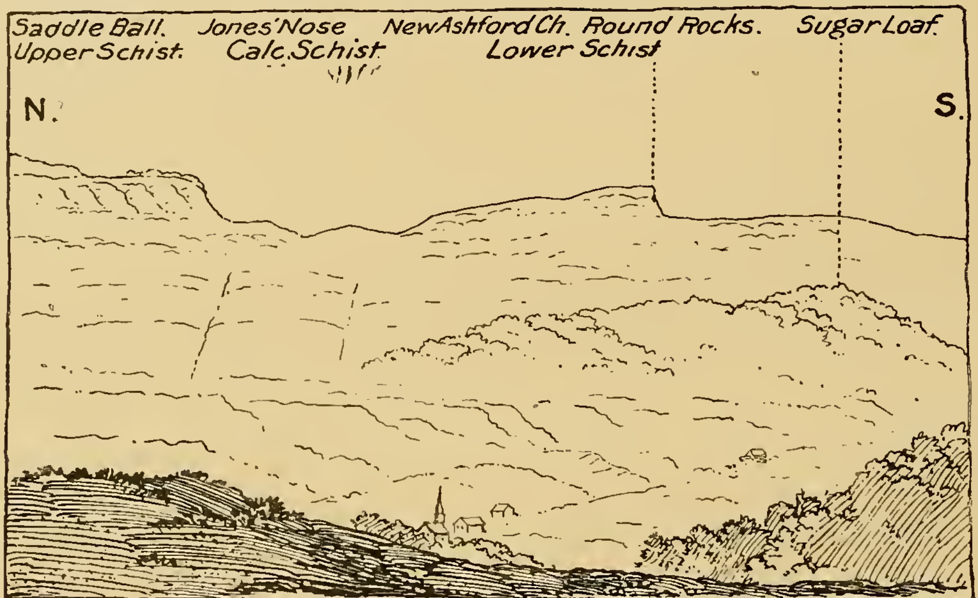


FIG. 74.—Outline sketch of Round rocks and the northern slope of Saddle Ball and Sugarloaf mountain from the west, locality 772 on East mountain, showing the hollow between Round rocks and Saddle Ball due to the erosion of the calcareous schist (Bellowspipe limestone); also the cliff at Round rocks in the Berkshire schist, and the upper bench on Saddle Ball in the Greylock schist.

noncalcareous schists. Some of these ravines are quite as steep and difficult of access as any in the Hopper.

The problematic upper bench on Saddle Ball (see Pl. XIII, Fig. 74 and Section K) is possibly due in part to the horizontal position of the strata along a portion of the slope, and possibly in part also to pre-glacial erosion. These benches and those on the long southeast spur of the same mountain may also be connected with the gentle northerly pitch of the south end of the great troughs. They require further study.

The saddle between Greylock summit and Saddle Ball seen for a great distance south (Pl. xv) is due to the synclinal structure of the central ridge, the westerly dip on the east side of Greylock, the easterly dip on the west side of Saddle Ball. The saddle in the central crest as seen from Mount Equinox, i. e., the north northwest, is due to the pitch of the sides of the central trough. (See Fig. 30 and Section Q.) The northeast to southwest trend of the ridge between the two summits and the northerly trend of the central ridge north of Greylock correspond to changes in the direction of the strike, but the general trend of East mountain does not conform to the strike of its strata.

The two depressions, alternating with three elevations, seen on the range

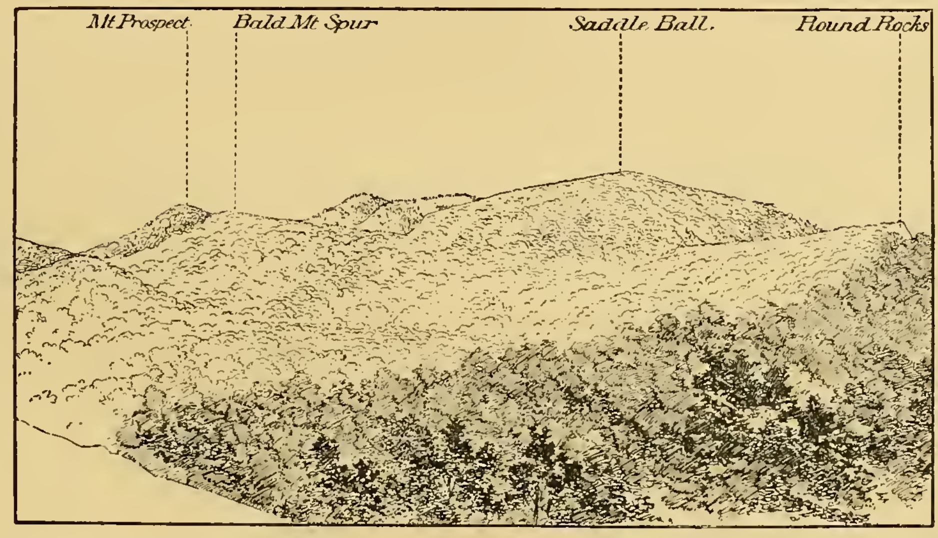


Fig. 75.—Sketch of the Greylock mass from the southwest (locality 1008, on north Potter mountain) showing the surface of the Bald mountain spur and of Round rocks pitching toward each other owing to the pitch of the synclinorial axis.

from Clarksburg mountain and the Stamford valley are due to the presence of the two belts of the upper limestone and calcareous schist on either side of the central ridge (Berkshire schist) one forming the Notch, the other "Wilbur's pasture," and the north to south part of the Hopper.

The gentle northerly slope of the surface from Round rocks to Jones's Nose (see Fig. 74, and Section Q), and the similar southerly slope of the top of the Bald mountain spur, as seen from North Potter mountain on the southwest (Fig. 75), are probably due to the trough structure of the entire mass, the former constituting a part of the northern trough of the great central syncline. To this structure are probably also due the long, steep southern face of Round rocks and the steep south side of Saddle Ball. The former is a very striking object in the landscape both from the east and west. (Compare Section Q with Pl. XIII and Fig. 74). An east to west system of joints and fractures growing out of the pitch may have aided glacial and other erosion at these points.

The great west spurs which characterize the west side of the range (Pl. XIII) are portions of the mass left by the erosion which chiseled out the Hopper and the hollows farther south, while the pleasing variety of surface features seen on the east side from Hoosac mountain (Pl. XII) is the result of the Berkshire schist forming a series of foothills between the upper and the lower limestone. Some of these are also shown in Pl. XV, the view from Lenox mountain. East of the summit, however, these schists have been eroded almost down to the level of the Stockbridge limestone, thus enabling one to look over from Hoosac mountain into the area of the Bellowspipe limestone and southwards for 2 miles to a point where the Berkshire schist rises from under the Bellowspipe limestone and hedges it in ("The Canoe" Pl. XII), forming several considerable masses, the pinnacle and the southeast spur of Bald mountain. These constitute the ridge between the northern and the southern trough of the eastern syncline and shut in the view. (Compare Pl. XII and Section P.)

A careful comparison of the topography and geology of the map, with the transverse and longitudinal sections, and the general views (Pls. XII, XIII, XV, and Figs. 30, 75) will show more clearly than words can the general structural relations of the Greylock mass to its surface features.

APPENDIX A.

STONE HILL, NEAR WILLIAMSTOWN.

This oft-studied and problematic locality has not yielded anything very remarkable.[1] Observations of strike and dip were made, typical rock specimens were collected and submitted to Mr. Wolff for microscopic examination. Three cross sections have been constructed, S, T, U (Fig. 76), and one longitudinal one, R′ (Pl. XXIII). The difficulties at Stone hill arise from the small number of outcrops and their entire absence at critical points.

The areal geology of the hill is indicated on the geologic map. The first question which arises is whether the mass of quartzite along the east side of West brook valley, apparently overlying the limestone, forms a part of the quartzite at the top of the hill. There is a gentle slope of arable land between the two, and a small limestone outcrop on the east side, at the north end of the westerly mass, has a foliation which strikes with the trend of this strip of cultivated land. It has therefore been conjectured that the two masses are separated by limestone, but the other supposition would be tenable.

The dips in the main mass of quartzite, on both sides and in the center, are easterly; but at the south end the dip (pitch?) is south, and a well marked southerly pitch occurs in the quartzose limestone at the southwest end of the hill (localities 1103–1105). A very high southerly pitch occurs also in the limestone a little farther south (locality 62) on the north side of the Green river bridge crossed by the road from Sweet's corners to South Williamstown. Here there is a small, sharp anticline with an almost vertical pitch. A southerly pitch occurs again in the schists at the north end of Deer hill. High up on the southeast side of Stone hill (locality 1106) an outcrop of quartzite with limestone north of it shows a southeast pitch. This, however, has been regarded as a quartzose part of the limestone, Formation €Ss. From all these facts the quartzite at the top of the south end of Stone hill appears to pitch under the limestone farther south and down the hill, and that limestone to pitch under the Berkshire schist of Deer hill. We thus have here in their normal succession, the Vermont formation, the Stockbridge limestone, and the Berkshire schist, and the relations which seem to exist between Clarksburg mountain (Oak hill) and the north end of the Greylock mass are repeated here between Stone hill and Deer

[1] See Emmons: Geology of the Second District of New York, pp. 145, 156, 159; Report on agriculture pp. 83–86. James D. Dana: Taconic rocks and stratigraphy, p. 406; Geology of Vermont and Berkshire, p. 206.

hill. (See sections Q and R′). These relations at the south end of the hill, together with the structure of Buxton hill and the northerly pitch observed by Mr. Hobbs at locality 2005, a little west of Buxton hill, lead to the supposition that the quartzite of the top of the hill, at the north end, pitches under the limestone at Williamstown.

The correctness of this conclusion is also rendered probable by the petrographic character of the Stone hill beds, which is similar to that of the Oak hill beds. On the east of Stone hill strata of micaceous feldspathic quartzite occur between those of massive quartzite (locality 627). In three localities a fine schist or phyllite of

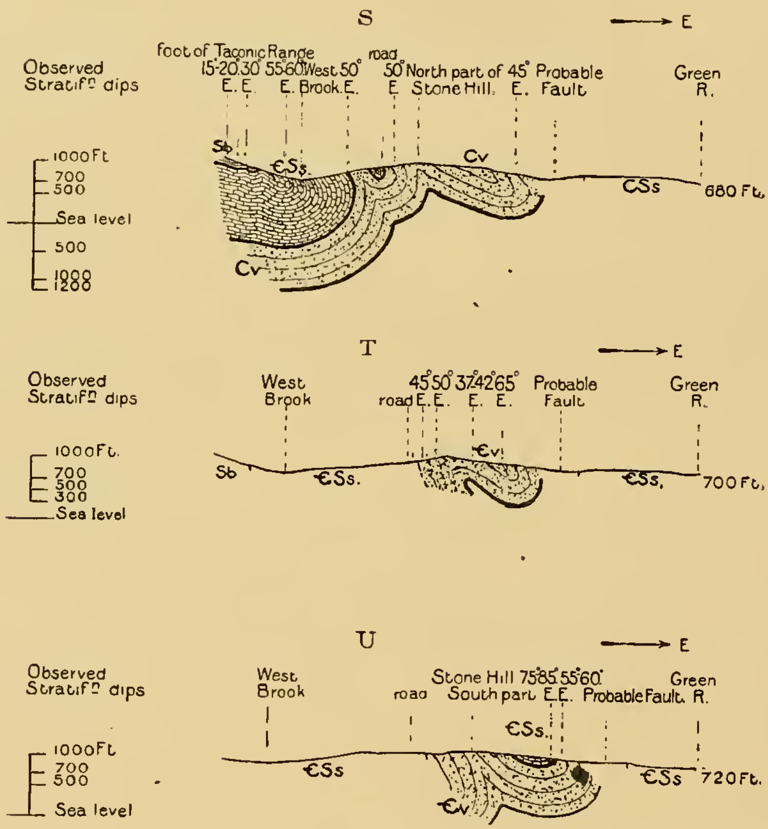


FIG. 76.—Cross-sections S, T, U, Stone Hill.

inconsiderable thickness appears. Towards the north end of the east side of the hill a blue quartz conglomerate, and a quartzite containing blue quartz and detrital feldspar occur.[1] Mr. Wolff's descriptions of these rocks are given beyond.

[1] Dewey: "Granitell of Kirwan, quartz, and feldspar. This aggregate forms extensive strata at the east base of Stone hill, the feldspar is diffused in grains through the quartz, and sometimes crystalline, forming porphyritic quartz. This aggregate is often compact and very hard, but frequently it is porous and hard, forming good millstones. Sometimes the quartz appears in such fragments that the stone resembles breccia." Am. Journal of Science, ser. I, vol. I, 1819, p. 343.

See also Emmons, American Geology, p. 16, on the conglomerate of the granular quartz at Oak hill.

In constructing transverse sections of Stone hill several difficulties present themselves. The quartzite with detrital blue quartz and feldspar, which may naturally be supposed to occur near the base of the quartzite and towards some underlying gneissoid rock, and which Emmons places at the base of his "granular quartz," occurs only on the east side of the hill dipping toward the limestone outcrops of Green river and Williamstown (Formation ЄSs). On the west side of the western mass of quartzite the rock is massive, and seems to be conformably underlain by the limestone of Formation ЄSs, but that quartzite we should expect to represent the upper part of the quartzite (Formation Єv).

One explanation of these facts would be that on the west the apparent superposition of the quartzite upon the limestone is the result of an overturn, while on the east the two rocks are separated, as Emmons supposed, by a fault.[1] Such a fault would be nearly, if not quite, on the line of the fault on the east side of Deer hill (Section G), and with that farther south near the west end of the Bald mountain spur (Section I) and also on a line with faults in southern Vermont at East Pownal. The highly contorted character of the limestone strata along Green river east of Stone hill, and in the village of Williamstown[2] also lend probability to such a hypothesis.

Upon this basis of fact and probability the folds in the Stone hill sections have been constructed. On the east side of Stone hill a fault is represented; the central portion of the hill consists of a syncline followed on the west by an anticline overturned to the west; the outlying masses of quartzite on the southeast and northwest sides of the hill involve two minor anticlines. All the folds have a southerly pitch at the south end of the hill and a northerly one at the north end.

The entire thickness of the Stone hill quartzite and its associated micaceous feldspathic rocks would thus measure between 800 and 900 feet. If a simple anticline be supposed it would measure about 1,300 feet, and if a monocline, as represented by E. Hitchcock in his Massachusetts section, about 2,600 feet.[3]

The rocks of Stone hill are frequently jointed; one of the systems of joints may possibly be connected with the pitch, as may also the occasional east to west joints and some of the secondary cleavage planes on Greylock. On the east side of the southern portion of the hill the massive quartzite is traversed by joints striking north 65° east, and dipping 65° to 75° northwesterly. On the east side of the central part the micaceous quartzite has a set of joints striking north 80° east and dipping 80° southerly, and another set striking north 20° west, and dipping 45° easterly. The dark pyritiferous quartzite (locality 18) near the top and center has joints striking north 72° east, and dipping 65° north-northwest.

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[1] See his Section 46 (Geology second district, New York, p. 145), in which he represents a fault immediately east of Stone hill, and another farther east along the western foot of the Greylock range.

[2] Dewey refers to the contortions here: Am. Jour. of Sci., ser. I, vol. 9, 1825, p. 19.

[3] Report Geol. of Vermont, vol. 2, pl. XV, fig. 5.

The following is Mr. J. E. Wolff's summary of his notes on the Stone hill microscopic sections:

STONE HILL ROCKS.

"We have in the quartzite series of Stone hill an interesting illustration of the share that the original detritus and the modification produced by mechanical and chemical agencies take in producing certain rocks.

"The quartzite varies microscopically from a fine-grained rock, composed to the eye of quartz grains and more or less mica to a coarse fragmental quartzite or fine-grained conglomerate (locality 628) in which angular fragments of feldspar and rather rounded masses or pebbles of blue quartz are visible; the latter grade insensibly into the granular white quartz forming the rest of the rock.

"Studied in the thin section the structure of the rocks is as follows: The large masses of blue quartz show in polarized light that they have been subjected to great pressure and strain, which has resulted in a partial or total breaking up of the original homogeneous quartz into a 'groundmass' or mosaic composed of extremely small particles of quartz in which are contained cores of cracked and strained quartz which are remnants of the original masses.[1] The comparatively large fragments of feldspar are seen to be in most cases microcline or a plagioclase feldspar, but sometimes without evidence of multiple twinning, and in that case probably orthoclase. The substance of the feldspar is cloudy, owing to kaolinization. The forms are sharply angular and evidently detrital. The remainder of the rock is a very fine-grained aggregate of little grains of quartz and rarer ones of feldspar, the latter being similar in character to the larger fragments of the same mineral. Irregular and interrupted layers of a colorless muscovite, which has the wavy 'interwoven' structural form characteristic of sericite, give the rock a lamination, the plane of which is parallel to the planes of crushing in the quartz, that is, at right angles to the pressure. When one of these layers of mica touches one of the large clastic feldspars, it often forks and completely surrounds the feldspar, the two parts joining again on the other side; accompanying this there is a thickening of the layer of mica around and near the feldspar, and sometimes litttle tongues of the mica, branching from the main mass outside, penetrate the feldspar, especially along cleavage cracks. It is therefore evident that the clastic feldspar exercised an influence on the formation of the mica and probably gave up part of its substance to form the latter. These large feldspars, like the quartz, are fractured and broken, the quartz aggregate of the 'groundmass' filling the fissures.

"The small feldspars of the 'groundmass' have in part the same characters as the large detrital ones, and in fact are often evidently derived from an adjacent large

[1] See Pl. x in Part II for an enlarged photograph of a thin section of this crushed blue quartz from Stone hill.

grain, but in part they have a more rounded form and show little trace of decomposition. In some of these grains there is a central core which is opaque owing to kaolinization (as is the case with the whole grain in the case of the large fragments) but surrounded by an outer rim of clear fresh feldspar material, which has the same crystallographic orientation as the inner core, the two forming one grain. If these grains are detrital, as they seem to be, there must have been a recrystallization of the old feldspar or a deposition of new feldspar around the old grain.[1]

"In certain fine-grained varieties of these Stone hill quartzites the amount of feldspar is very large, and it is difficult to say whether these small grains are in their original detrital shape or are metamorphic.

"In some cases the large clastic feldspar masses are aggregates of several individual grains of feldspar, forming thus a rock fragment which resembles closely the coarse granitoid gneiss found on Clarksburg mountain to the northeast and Hoosac mountain to the east, which underlies the whole Taconic series. Hence there is a possible derivation for the material of the quartzite.

"Prisms of tourmaline are common in the rock, and there are occasional rounded grains of zircon. Secondary limonite often stains the rock yellow. Grains of pyrite are abundant in some specimens (locality 18, near top of hill), and in one there is a large amount of calcite present in small grains and irregular masses.

"These quartzites seem to derive their present materials from two sources, the original detrital material and the material produced from this, at least in part, by mechanical and chemical agencies. The blue quartz 'pebbles' (locality 628, east side) may be regarded as pebbles whose original outlines have been largely obliterated by mechanical deformation; the large feldspar fragments are undoubtedly detrital and so is the zircon. The cement or 'groundmass' is composed of detrital quartz and feldspar mixed with an unknown amount of the same minerals formed in situ and by muscovite in large part and tourmaline produced by metamorphism.

"The distinction made here between clastic and metamorphic feldspar is well marked in the extremes as found on the clastic side in these rocks; on the metamorphic side in the albite of the schists of Greylock and Hoosac mountains, and analogous feldspars of the gneisses of Hoosac mountain."

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[1] Cf. Irving and Van Hise, Bull. U. S. Geol. Survey No. 8, p. 44.

APPENDIX B.

NEW ASHFORD.

There is an area of between 3 and 4 square miles south and east of the village of New Ashford, within which nearly all the structural and areal features that characterize the Greylock mass are repeated on a small scale and within easy reach. Pl. I shows the geology of this tract. Section M traverses it. Fig. 74 gives a view of the greater portion of it and of Sugarloaf mountain which covers a large part of the area. This little schist mountain, the synclinal structure of which has already been alluded to, is entirely surrounded as well as underlain by limestone. It forms a conspicuous object in the landscape, views of it from the north (Fig. 30) and the south (Pl. XV) showing the depression on either side of it corresponding to the limestone.

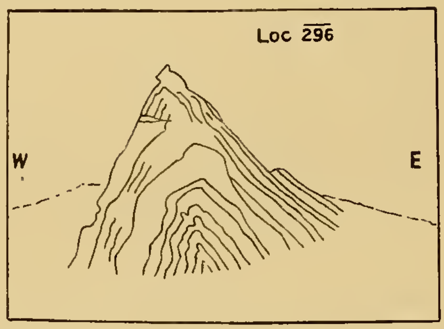

Fig. 77.—Apex of the main anticline of Stockbridge limestone protruding through the Berkshire schist at Quarry hill, New Ashford. Height, 8 feet. Southern side. See locality 296, Fig. 78.

A line of cliffs, masked, however, by foliage, traverses its south end from east to west, rising above the limestone which pitches under it. On the west side of Sugarloaf the synclinal structure is concealed in most of the limestone out-crops by cleavage foliation. (See Fig. 37.) A northerly pitch is well observed at the south end in some of the minor folds (see Fig. 60), as well as a southerly pitch in the schist at the north end. Section R″, which follows the synclinal axis of Sugarloaf, shows the trough structure of that mountain. Another trough exists in the schist mass south of it.

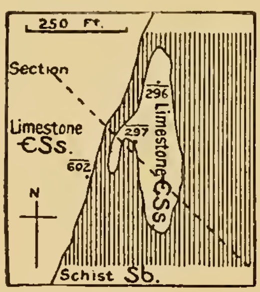

Fig. 78.—Geologic map of Quarry hill, New Ashford.

Several isolated schist masses cap the limestone folds along the foot of the mountain on the south. The phenomena of cleavage and stratification in one of these have been shown in Fig. 35.

On Quarry hill the converse of the structure presented by Sugarloaf mountain appears. A limestone anticline with subordinate folds protrudes through the schist.

The diagrams (Figs. 77, 78, 79) represent the area, size, and structure of this anticline, and Figs. 32, 33, 34 show the cleavage phenomena in it.

The schists at the foot of the hill toward the village form part of those of East mountain (Beach hill). The easterly cleavage would easily mislead one here into a wrong interpretation of the relations. The broad area of limestone in which the old

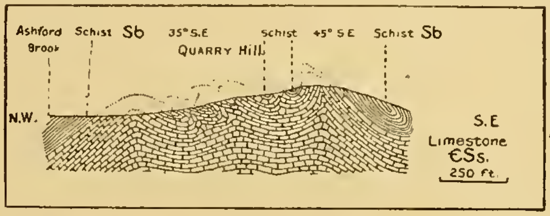

Fig. 79.—Section through Quarry hill, New Ashford, showing the structural relations of the Stockbridge limestone and Berkshire schist.

quarries lie, forms an anticline, and the schists referred to overlie its base with a westerly dip. It is uncertain whether the section given by Emmons (Geology of second district, p. 155), through the New Ashford marble quarry, relates to this quarry or to one of several others in the vicinity.

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